9-10-2018

The Relationship Between Spinal Mobility Measures and Shoulder and Elbow Injury in College Baseball Pitchers

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ABSTRACT

Shoulder and elbow throwing-related injuries in baseball players have been on the rise for the past three decades. Prevention programs are founded on the knowledge of important risk factors, but the injury risk model for throwing-related shoulder and elbow injuries is incomplete. **Purpose:** To investigate neck mobility and postural measures as risk factors for throwing-related shoulder and elbow injury in college baseball players and assess variability in these measures during the season. **Methods:** Forty-nine college baseball pitchers were enrolled prior to the season. Posture, neck mobility, and glenohumeral passive motion were measured at preseason and mid-season using the Inclinometric Kyphosis Measure (IKM), CROM®, Cervical Flexion Rotation Test, and digital inclinometer, respectively. Time-loss (days lost to shoulder or elbow injury) and pitch counts were recorded, and pitchers completed the Functional Arm Scale for Throwers Pitcher Module (FAST-PM) at baseline and throughout the season. Pitchers were dichotomized into injured and uninjured groups based on time-loss >7 days and FAST-PM >10. Differences between groups were analyzed with the Mann-Whitney U test. ROC curves were generated, and diagnostic values and risk ratios (RR) were calculated to assess the predictive utility of the physical measures. Preseason and mid-season measures were compared with repeated-measures MANCOVA with pitch count as a covariate, and a one-Way ANOVA was performed to evaluate group differences in change scores. **Results**: Ten pitchers (20.4%) sustained a time-loss injury. Dominant Cervical Flexion Rotation Test of <39° resulted in over 9 times increased risk of time-loss injury (RR=9.38). Dominant Cervical Flexion Rotation Test of <39°, Cervical Flexion Range of Motion < 64°, and mass >86.86 kg were associated with increased risk of injury on the FAST-PM (RR=4.05, RR=8.90, RR=10.42, respectively). Three pitchers withdrew from mid-season testing. There were significant decreases in bilateral Cervical Sidebending motion ($p=.000$; $p=.009$), Cervical Flexion motion ($p=.023$), and Cued IKM ($p=.001$). There were no group differences in variability for time-loss or FAST-PM.

Conclusions: College baseball pitchers with less preseason neck mobility had increased risk of time-loss and patient-reported shoulder and elbow pain and disability. Neck mobility decreased from preseason to midseason, and injured pitchers tended to display less cervical mobility.

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A Dissertation

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

at the

University of Connecticut

2018

APPROVAL PAGE

Doctor of Philosophy Dissertation

The Relationship Between Spinal Mobility Measures and Shoulder and Elbow Injury in College Baseball Pitchers

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CHAPTER I: REVIEW OF THE LITERATURE

Purpose

The purpose of this literature review is to provide an overview of 1) the public health impact of throwing-related shoulder and elbow injuries in baseball players, 2) risk factors for throwing-related shoulder and elbow injuries across baseball competition levels, and 3) gaps in the literature with regards to the current status of injury risk prediction and prevention of throwing-related shoulder and elbow injuries in baseball players.

Participation

Baseball is America's pastime with more than 15 million adults and children in the United States participating in baseball annually.[31] Seventeen percent of the US youth and adolescent population play baseball, and the National Federation of High School Associations reports that over 491,000 boys played high school baseball in 2017.[61] When 2 and 4 year colleges are considered, a total of 48,408 student athletes play baseball at the collegiate level each season,[42] and in the professional ranks, there are more than 6500 players on Minor and Major League Baseball rosters.[16] Baseball is also a popular sport outside of the US with 35 million participants on all five continents according to the International Federation of Baseball, and littleleague.org boasts 2.2 million Little League Baseball participants worldwide.

Although baseball is considered safe relative to contact sports such as football and hockey, baseball participation still comes with a risk of injury, and pitchers are particularly vulnerable at all levels of competition. Reports from multiple studies across competition levels support the notion that the most commonly injured body regions in baseball are the shoulder and elbow, the majority of these are overuse injuries associated with throwing, and most throwing-related injuries are attributed to pitching.[21,47,70-1] At the youth and younger adolescent level, the most frequently observed throwing-related injuries are apophysitis (Little League Shoulder/Elbow), medial epicondylitis, and osteochondrosis or osteochondritis dissecans in the lateral elbow.[52,86] In older adolescents (high school) and adults, glenohumeral internal impingement, injury to the articular surface of the rotator cuff, and Superior Labral Anterior-Posterior (SLAP) lesions may be seen at the shoulder, while at the elbow, the most common injury is ulnar collateral ligament injury.[15-7,86] Despite efforts at prevention, the last three decades have seen a steady increase in the incidence and prevalence of serious shoulder and elbow injuries in baseball pitchers with the most concerning trends occurring in the youth and high school age groups.[17,56,70]

Injury Data

In order to interpret injury frequency data, it is important to understand the definitions of injury in epidemiological studies of baseball injury and integrity of the sources of data. Most studies report injury based on time loss data, and accordingly, current definitions of injury meet the following three criteria: "(1) occurs as the result of an organized high school baseball practice or competition, (2) requires medical attention by an athletic trainer (AT) or physician, and (3) results in restriction of the athlete's participation for at least 1 day beyond the date of injury."[71] The statistics reported below are based on time-loss data unless specifically noted.

While most studies report sports injury incidence in terms of missed athlete exposures, baseball athletes often sustain injuries that result in pain and disability but not missed time. To this end, Kerr et al[48] studied "non-time-loss" (NTL) injuries in high school and college athletes to better represent the burden of injury on athletes and the health care systems that manage them. An NTL injury is defined as any injury that was evaluated or treated by an AT or physician but did not result in restriction from participation beyond the day of injury.

Most injury statistics reported in the last decade are calculated for high school and college baseball players based on data extracted from the National Athletic Treatment, Injury and Outcomes Network Surveillance Program (RIO) and National Collegiate Athletic Association Injury Surveillance Program (ISP) databases.[47] The accuracy of these data is dependent upon compliance with reporting by each school's AT, and not all schools participate. Additionally, without an AT present at all practices and games, the number of incident cases (especially NTL) may be under reported. However, these databases generally represent a robust, convenience sample that provides the best overall view of sport injury at the high school and college levels in the US. Until 2011, professional baseball did not have a centralized database to analyze injury trends to inform the health and safety of the players. In 2011, Major League Baseball and the Major League Baseball Players Association, in cooperation with Johns Hopkins University, established the Health and Injury Tracking System (HITS) database to track injuries across professional baseball.[69] Future epidemiological reports based on the HITS surveillance system will offer an improved picture of the magnitude and trends in injury incidence and prevalence in professional players.

Incidence and Prevalence

<u>Youth</u>

Without a national database, data regarding youth injury rates are derived from survey and small cohort studies. Two Little League surveys in the 1970's (n=715) found that 17-20% of players age 11-12 reported throwing-related shoulder or elbow pain.[38] Lyman et al 2001[52] was the first longitudinal study to examine throwing-related injuries in 298 youth baseball pitchers surveyed over two seasons. Shoulder or elbow pain was reported by 47% of the pitchers; the authors reported that 26% of the cohort reported elbow pain and 32% reported shoulder pain during or after pitching. The recent incidence of elbow pain in youth players has been estimated at 1-1.5 per 1000 AEs, [78,80] and experts report an upward trend in injury. In a longitudinal, annual survey study of a cohort of 481 players age 9-14, Fleisig et al[31] reported a fivefold increase in serious shoulder and elbow injuries among youth baseball players from 2000-2010 with 5% of players sustaining an injury requiring shoulder or elbow surgery or retirement from baseball.

Adolescent/High School

Based on RIO data over a 10-year period from 2004-05 to 2014-15, Pytiak et al[71] found an all cause injury incidence of .92 per 10,000 AE in high school baseball players. A well-designed analysis of NTL injury by Kerr et al[48] reported an incidence of 4.64 per 1,000 AE in high school baseball players from 2011- 2014 with 38.2% of those injuries occurring at the shoulder or elbow. Fifty-one per cent of these injuries resulted in loss of play for a week or more. According to Robinson et al[76], injury estimates for High School (HS) baseball players included 64,229 shoulder injuries nationally over 7 years (2005-2006 through 2012-2013) with a Relative Risk (RR) of 1.73 (1.29–2.32) of sustaining a throwing-related shoulder injury.[76] At the elbow, 57% of ulnar collateral ligament reconstruction (UCL-R) surgeries in the US from 2007-2011 were performed on 15 to 19-year-old males, and the incidence of UCL-R in this age group increased an average of 9% per year.[27] Moreover, a recent New York state review predicted that in the next decade, the average annual incidence of (UCL-R) due to throwing injury in males age 15-19 will double from 6.3 per 100,000 to 14.6 per 100,000.[56] The authors noted a disturbing trend of an average annual increase in number of UCL-R performed of 18%, a cumulative increase of 343% over 10 years, and subsequent decrease in average age at surgery from 20.5 to 19.1 years.[56]

Collegiate

College baseball players sustain athletic injuries at an average rate of 4.7 per 1,000 AE.[21,47] The number of incident cases between 2009-10 and 2014-15 was 13,292, and 24% of those injuries were serious enough to require > 7 days of missed play.[47] In a review of injuries in college baseball players between1988-2015, Dick et al[21] found that 45% of injuries occurred in the shoulder and elbow, and pitching accounted for 70% of these injuries. This is consistent with a small, cohort study which found that upper extremity injuries accounted for 75% of time loss during a competitive season.[54] Similarly, Kay et al[44] reported that 45% of *serious* college baseball injuries occur in the shoulder (17.8%) or elbow (27.8%), resulting in loss of >21 days of participation.

Baseball is the men's college sport with greatest proportion of non-time-loss injuries (59.1%).[48] Shoulder and elbow injuries are responsible for 32.8% of these injuries, and unlike most other men's college sports, more injuries occur during competition than practice with 2-3 times more injuries occurring during games.[21,47] Not surprisingly, Division I has the highest game and practice injury rates per 1,000 AE (6.64 and 2.34, respectively) followed by Division II (5.36 and 1.47) and Division III (4.85 and 1.59).[47]

Professional

Shoulder and elbow injuries accounted for more than 40% of injuries in Major League Baseball players from 1998-2015 at an indirect cost (lost salary) of $414,000,000 dollars over the 17-year period.[17] Elbow injuries alone account for an annual average of 44,519 days lost in Major League Baseball, and a recent survey of 5,088 professional players by Conte et al[16] found that 25% of current major league pitchers and 16% of minor league pitchers have sustained a serious elbow injury requiring ulnar collateral ligament reconstruction (UCL-R). There is an overall prevalence of UCL-R in professional baseball players of 10% with a higher prevalence in pitchers (16%) versus non-pitchers (3%).[16] It is important to note that players who left baseball due to elbow or shoulder pain are not represented in these prevalence statistics, so this may underrepresent the frequency of injury to baseball pitchers.

Clearly, the problem of throwing-related shoulder and elbow injury is not isolated to professional athletes, and increased exposure with the emergence of youth sport specialization has contributed to increased throwing-related injury incidence at all age levels.[41] There has been a staggering increase in serious elbow injury particularly in pitchers at the high school, college, and professional levels leading one prominent surgeon to label it an "epidemic."[16,31,57] The increase in the number of surgeries and percent of surgeries in young baseball pitchers should be interpreted with caution; this may be indicative of an actual increase in injury incidence, but improved diagnostics and access to surgery may also play a role. On the other hand, since incidence and prevalence of UCL injury are often measured by UCL-R, the actual incidence and prevalence of UCL injury (not requiring surgery) is likely underestimated.

Consequences of Injury

Sports injury has both short and long term consequences for athletes and their teams in terms of pain, disability, performance, psychosocial well-being, and financial burden. Significant costs are associated with throwing-related arm injuries, which can impose a financial burden on the athlete, his or her family, or team/organization. The average direct medical cost in 2015 for overuse arm injuries in high school athletes was estimated at $466 per episode.[59] When total cost is considered, including reduced quality of life and lost work time for the athlete and his or her family, the total approaches $8,000. When surgery is required, the costs are even greater. For players requiring

UCL-R, the surgery cost alone is approximately $15,000, and the costs of 9-12 month rehabilitation bring the total to $20-25,000.[37]

There are other indirect economic costs as well. In Major League Baseball in 2015, elbow and shoulder injuries accounted for 38.8% of injuries resulting in time on the disabled list.[9] Time on the disabled list cost MLB organizations over $420 million dollars of lost salary in 2015 with shoulder and elbow injuries accounting for 54%.[17] With significant disability, failure to respond to conservative treatment, prolonged recovery, and increasing prevalence, Conte et al[16] suggested that UCL injury is currently the most costly of all baseball injuries.

More importantly, though, throwing-related injuries impact the health and lives of athletes at all ages. Consequences include time lost from baseball participation, school and play, impaired performance, permanent pain and disability, and lower quality of life. According to Osbahr et al[20], 10-20% of pitchers who have UCL-R do not return to pre-surgery levels of play. Additionally, adolescent athletes with self-reported recent injuries have lower scores not only in the areas of physical functioning and pain, but also in social and global functioning.[43]

Risk Factors for Shoulder and Elbow Injury in Baseball Players

Risk factors are broadly categorized as modifiable and non-modifiable.[58] Non-modifiable risk factors are cannot be changed or altered through interventions but represent important components of the risk profile. Modifiable risk factors, on the other hand, can be altered with interventions and are therefore primary targets for prevention. Identification of modifiable risk factors through screening can assist clinicians in identifying athletes at increased risk of developing throwing-related injury and developing intervention strategies to reduce risk. Risk factors may also be described as intrinsic or extrinsic.[58] Extrinsic risk factors are imposed on the athlete, while intrinsic factors are characteristics inherent and unique to the individual athlete.

Exposure related factors known to contribute to throwing-related injury in baseball players include prior arm injury, pitch volume, pitch velocity, poor mechanics, and pitching with arm pain and fatigue.[104] Organizations like Little League Baseball and some state high school athletic associations have instituted pitch count restrictions and mandatory rest periods in an attempt to protect pitchers by limiting exposure. While overuse is the primary risk factor, physical measures including glenohumeral range of motion, rotator cuff strength, and balance are also reported to be associated with upper extremity injury in pitchers.[35,41,56,83-5] The following is an overview of known risk factors.

Non-Modifiable Risk Factors: *Extrinsic*

In baseball pitchers, mode of play and pitcher position influence injury risk. Mode of play refers to practice versus competition, and throwing-related shoulder and elbow injuries are more likely to occur during game situations in high school, college, and professional play.[47] Across all levels of competition, pitcher are at greater risk of shoulder and elbow pain than position players. A retrospective study of former Little League World Series pitchers who subsequently played professionally found that 23.1% of those who pitched professionally had UCL-R procedures while none of those who also played other positions required UCL-R ($P = .008$).[26] Similarly, an observational study of 294 9-12 year old baseball players found that pitchers had 4.5 times the odds of sustaining a structural injury versus fielders (OR=4.50 (2.42-8.37).[39] At the college level, pitchers have historically suffered more injuries with 69% of shoulder injuries occurring in pitchers.[54] , and professional pitchers have 34% higher incidence rates for injury compared with fielders (IRR = 1.34; 95% CI = 1.25, 1.44).[70] This suggests that prevention resources should be targeted to players in high risk positions such as pitching.

Non-Modifiable Risk Factors: *Intrinsic*

Age

Universally, adolescents are consistently at greater risk for athletic injury due to the rapid growth and changes to the musculoskeletal system coupled with associated increases in participation frequency and intensity. Historically, experts have believed that increasing age and exposure increase a pitcher's risk of throwing-related injury, however, it is unclear whether age is merely a proxy for exposure.[53] Harada et al[39] found that age was an independent risk factor for elbow injury confirmed on imaging with an odds ratio (95% confidence interval) of 2.82 (1.30-6.10) for players >11 years of age.

Height

Pitchers who are taller and heavier have increased risk of injury at the youth and high school levels. In a case control study of youth players 9-12 years old, players with standing height exceeding 150 cm had twice the odds of sustaining a structural elbow injury 2.02 (1.07-3.82).[53] Olsen et al[64] compared healthy 14-20 year-old pitchers to those undergoing UCL-R and found that pitchers who were taller and heavier had a greater risk of UCL injury.

Height is a non-modifiable risk factor, but in the youth and high school age groups it does change across a season and that change may influence injury risk. Harada et al[39] found that 35% of the participants demonstrated significant changes in height and weight over the course of 1 year.

History of Previous injury

Structural and neurophysiological changes secondary to an injury or failure to adequately rehabilitate may predispose an athlete to re-injury or secondary injury. Many prospective studies of baseball injury risk exclude players with past injury history making it difficult to assess the role of prior injury.[(83,87)] Conte concluded that prior shoulder or elbow surgery was NOT a risk factor for UCL-R in professional athletes.[16]

Modifiable Risk Factors : Extrinsic

Since overuse is a primary driver of throwing-related shoulder and elbow injury, number of athlete exposures is considered a primary risk factor. The repetitive forces applied to the shoulder and elbow may result in cumulative trauma to bone and connective tissue structures, and when coupled with physical impairments such as GIRD, set the stage for future serious injury. Cultures that embrace early sport specialization in youth have led to increased cumulative exposure as youth and high school players participate in multiple seasons and on multiple teams. This dramatically increases the number of annual exposures in a skeletally immature athlete. In baseball players, exposure related risk factors include pitches per game, pitch volume, pitch type, playing on multiple teams, rules of the game (i.e. 12 second rule for pitchers), and institutional policies (i.e. NCAA games per week)[11] Traditionally, there have been a variety of measures used to define exposure, but the most accurate way to capture acute and cumulative exposure in pitchers is measurement of pitch count (per game/week) and pitch volume across a season or year.[96]

Pitch volume, type, and velocity

<u>Youth</u>

Fleisig and colleagues[31] conducted a 10-year longitudinal study of 481 youth baseball players age 9-14 years old. The authors found that those who pitched more than 100 innings per year were 3.5 times more likely to suffer a serious throwing-related shoulder or elbow injury requiring surgery or retirement from pitching (95%CI 1.16,10.44). Lyman et al[52] did not find that innings pitched correlated with injury, but pitch count was a relevant risk factor as pitchers who threw more than 600 pitches in a year were 2 times more likely to suffer elbow pain, and throwing more than 75 pitches in an outing increased the odds of elbow pain by 56% (OR=1.56; 95%CI.0.89-2.75) with 3.22 times the odds of shoulder pain (OR=3.22; 95% CI 1.84-5.61).[52] Additionally, former Little League World Series pitchers who exceeded pitch counts were more likely to require surgery as professional players (p=.009). Days of rest appears to play a role as well, as youth pitchers who trained seven days/week had nearly twice the odds of sustaining an elbow injury (OR=1.96; 95% CI 1.02-3.79)[39]

Despite much concern about increased injury risk for youth who throw curveballs, the majority of research does not support pitch type as a risk factor at the youth level.[36] Neither Lyman et al[52] nor Fleisig et al[31] reported an increased risk in youth players who throw curveballs, and only one retrospective study has demonstrated an increased risk of shoulder pain (52%) in youth pitchers throwing curveballs.[53]

Adolescent/High School

In a retrospective case control study, adolescent pitchers who pitched more than 80 pitches per appearance on average had approximately fourfold increased risk of shoulder or elbow surgery due to overuse injury (OR=3.83; 95% CI1.36-10.77).[64] Adolescent pitchers who played more than 8 months during the year had five times the risk approximately of sustaining a serious elbow or shoulder injury (OR=5.05; 1.39-18.32), and those who regularly threw >85 mph had an OR of 2.58 (95% CI .94-7.02).[6] In a separate study, odds of medial elbow injury were nearly doubled in junior pitchers who threw > 100 throws per day (OR, 1.936; 95% CI, 1.072-3.497).[78]

Collegiate

In an attempt to speed up play and reduce the length of games, Major League Baseball recently instituted a new rule that limited the time the pitcher has to deliver the ball to 12 seconds. Critics worry that the reduced time frame between pitches could result in higher injury rates. The only study to examine this effect is a small, collegiate study of 7 pitchers who threw a simulated seven-inning game with rest periods of 8, 12, or 20 seconds.[105] Researchers found that decreasing the rest interval from 20 to 12 seconds or less resulted in increases in muscle damage and inflammation that persisted beyond 48 hours and early-onset reduction in pitching performance.

Professional

A retrospective study of cumulative work in professional pitchers (games pitched, total innings pitched, total pitches thrown, innings pitched per game, and pitches thrown per game) did not find it to be a significant predictor for future injury.[45] However, pitch type may be a unique predictor of UCL injury. Keller et al[46] studied 83 pitchers who had undergone UCL-R and found that they tended to pitch a significantly higher percentage of fastballs than healthy pitchers. Pitchers who threw more than 48% fastballs required UCL-R (p=.006), and there was a 2% increase in risk for UCL injury for every 1% increase in fastballs thrown (1.02 (1.00-1.03), p=.035).[46]

Modifiable Risk Factors: Intrinsic

A number of physical factors are known to increase individual risk of throwing-related shoulder and elbow injury. Improper throwing mechanics[11] and impairment in physical measures such as glenohumeral range of motion[81-2,88], rotator cuff strength[87], and balance[35,73] are associated with injury risk, but the extent of the risk varies across age and competition levels.

The majority of physical risk factor research in baseball has centered on physical characteristics of the shoulder, particularly passive range of motion. The most extensive focus has been on glenohumeral internal rotation deficit (GIRD) as a risk factor for arm injury in athletes, but recent studies with conflicting results have called into question the relevance.[10,78,96] Loss of glenohumeral internal range of motion is an adaptation in response to repetitive throwing and generally represents a shift in the arc of total rotation. Over time, baseball players develop a side-to-side difference in glenohumeral IR ROM in the throwing arm which is accompanied by a corresponding increase in glenohumeral external rotation necessary for successful pitching.[4,9,14,16] This deficit increases over the course of a season[33,77,84] and acutely after a bout of pitching.[75] The pathogenesis of GIRD has been attributed to activity related factors in response to repetitive throwing including osseous adaptations of the humerus and glenoid[61], thickening and contracture of the posterior capsule[91], and shortening of posterior cuff muscles.[96] Interestingly, Whitely et al[99] studied adolescent pitchers and found that *non-dominant* humeral torsion was a significant contributor to injury risk. This suggests a genetic component to injury risk in addition to the activity related factors.

Some authors contend that the accompanying alteration in joint mechanics may be pathological and increase physical stress on the shoulder and elbow, while others consider GIRD to be pathological only when accompanied by a concurrent limitation in total rotation range of motion. This may represent a more clinically useful characterization. The following section reviews modifiable physical risk factors across age levels.

Glenohumeral ROM

Youth

Shanley et al[84] investigated preseason internal rotation range of motion (IR ROM) screening as a predictor of throwing related injury in 8-12 year-old pitchers. The injured group had a mean deficit of 8°, and there was no relationship between any type of IR ROM deficit and injury risk. Similarly, there was no relationship between IR ROM and injury risk in the prospective study by Harada et al; however, the authors reported that external rotation ROM less than 130° was associated with twice the risk of elbow injury (OR=1.98 (1.01-

3.87). Therefore, it appears that external rotation, rather than internal rotation, may be more important in this age group.

<u>Adolescent/High School</u>

There is conflicting evidence regarding the utility of glenohumeral ROM as a predictor of throwing related injury in this population. Shitara et al[29] performed a multivariate analysis on 105 high school baseball pitchers with preseason glenohumeral IR ROM as an explanatory variable. There was a linear increase in risk of injury with decreased IR ROM of 5°, 10°, and 15°, and 20°, and a decrease in dominant arm IR ROM of 20° was associated with 2.7 times greater risk of sustaining a throwing related arm injury disabling the pitcher for at least 8 days. However, no significant differences were observed between groups in IR ROM *deficit* with an observed 10% deficit in uninjured players and 9% in injured players. Although GIRD (a deficit) was not predictive of injury, the authors concluded that the most important finding of the study was that preseason IR ROM of the dominant shoulder was an independent predictor of shoulder and elbow injury.

Shanley et al[83-4] authored two studies which concluded that IR ROM deficit is predictive of throwing related injury. Baseball players with ≥25° deficit in IR ROM of the dominant arm had 5 times greater risk of injury in players in one cohort. The more recent report observed that injured adolescent pitchers had a mean deficit of 18° versus 11° in the non-injured group, and pitchers with a deficit of >13° had 6 times greater risk of throwing related injury (RR 5.82; 95% CI(1.6-20.9). Additionally, a side-to-side difference of horizontal adduction (HA) > 15° was able to discriminate between injured and uninjured adolescent pitchers (AUC = 0.71; P = .02), and adolescent pitchers with a side-to-side difference of HA >15° were at 4x greater risk of an overuse arm injury than those with <15° difference (RR 4.1; 95% CI (1.2-13.9).[83] External rotation ROM and total rotation ROM were not significant factors. The variability in magnitude of risk between the Shitara and Shanley studies may be due to sample selection, difference in classification of "injury", and different analytical approaches.

Two additional prospective studies did not find any glenohumeral ROM measures to be associated with risk of medial elbow injury.[68,78]

Confounding the information regarding GIRD, Tyler et al[96] studied a cohort of 101 high school pitchers and found that those with GIRD had a *reduced* risk of throwing related injury. The RR for injury for pitchers with 0° IR ROM deficit was 4.85 (95% CI, 1.01-23.29) compared to pitchers with > 20° loss. As in the Shanley et al[83] study, external rotation ROM and total rotation ROM were not related to risk of injury. The authors proposed that pitchers without ROM loss might have had less exposure resulting in lack of adaptation to the pitching motion. An alternate explanation for the conflicting results is the calculation of injury incidence with pitch volume as the denominator.

Collegiate

There are no prospective studies examining glenohumeral ROM and injury risk in college baseball pitchers. A case control study of 67 Division college baseball players found injured players demonstrated a loss of total rotation ROM of 9.6° in their dominant arm as compared to their non-dominant arms, while uninjured players had no side to side difference.[77] In addition, humeral retroversion is closely related to IR ROM, and a case control study of 40 college baseball pitchers by Myers et al[61] showed that the difference in humeral retroversion between the dominant and non-dominant arms showed fair ability to discriminate between those pitchers with a history of elbow injury and those without (AUC=.74, p=.027). This justifies investigation of IR ROM as a possible risk factor at the collegiate level.

Professional

Wilk et al studied GIRD as a dichotomous variable and found that pitchers with GIRD did not have an increased risk for either shoulder or elbow injury.[101-2] Injury rates for players with GIRD (17% shoulder and 14% elbow) were not statistically different from injury rates in pitchers without GIRD (14% shoulder and 13% elbow).[37,38]

Other motions at the shoulder proved to be risk factors for elbow injury at the major league level. A shoulder flexion deficit of >5° and Total rotation ROM deficit of >5° increased the odds of being placed on the disabled list by 2.8 (95% CI (1.3-5.9), P=.008) and 2.6 (95% CI (1.3-5.4), P= .007), respectively.[102] Pitchers with external rotation deficits were at increased odds of shoulder injury requiring time on the disabled list (OR=2.2, 95%CI (1.2-4.1) P= .014)

and were also more likely to undergo shoulder surgery (OR=4.0, 95%CI (1.5-12.6) P=.005).[101]

The variability in the evidence regarding glenohumeral ROM is not entirely surprising. Interpretation of the literature is hindered by a number of factors including differences in measurement technique, level of exposure of the cohort, definitions of injury, calculation of injury rates, and analytical approach. For example, the definition of injury at the HS level ranged from any shoulder or elbow condition that resulted in one missed game or practice to greater than one week missed. Additionally, Shanley et al[83-4] and Shitara et al[87] calculated injury rates as incidence per 1000 AE, while Tyler et al[96] used incidence per 1000 pitches.

Additionally, each age level may present with a unique model for injury risk. For instance, the combination of factors such as rapid growth, increasing velocity, and moving to larger diamond may be important considerations at the high school level.

Given the increased load volume on connective tissue structures, it is possible that adolescent athletes have a lower threshold for tolerating impairments as they relate to injury risk than youth who are less exposed and professional athletes who are skeletally mature.

Scapular dyskinesia

There are no studies suggesting that scapular dyskinesia contributes to injury risk at any age or competition level. Scapular dyskinesia categorized as "yes/no" on visual inspection was associated with a RR of .60(95% CI .15-2.38) for suffering an elbow injury that resulted in >7 days time loss in youth players, and Myers et al[61] found no significant difference between injured and uninjured high school pitchers despite a typical injury incidence.

Playing with pain or fatigue

Playing with pain or arm fatigue is a consistent finding among baseball pitchers, and given the nature of overuse injury combined with pressure to perform, this is not surprising.

Youth

Youth and adolescent pitchers (n=754) were surveyed regarding "risk prone" pitching activities.[104] Pitchers who stated they OFTEN pitched with arm fatigue had an adjusted OR of 7.88 (3.88-15.9, p=.001), and those who OFTEN had arm pain while pitching had 7.5 times the odds of sustaining an elbow or shoulder injury (OR=7.50; 3.47-16.21 p=001).

Adolescent/High School

In a case control study of 140 pitchers, more than 50% of injured pitchers regularly played with arm fatigue as compared to 11% of the uninjured group (p<.001) resulting in an OR= 36.18(5.92-221.22) for shoulder or elbow surgery.[55] Sixty-seven per cent of the injured group reported continued pitching despite arm pain versus 42% in the uninjured group (p<.01). A survey of high school pitchers found that 11% of 8-18 year-old pitchers reported playing with pain, and only 26% said that their arm never hurt during or after pitching.[55]

Models for Injury Risk Prediction and Prevention

In 1992, van Mechelen proposed a model to guide the development of prevention programs (Figure 1).[97] Knowledge of mechanisms and key modifiable risk factors is a prerequisite to creating and implementing effective prevention programs. However, this model proved simplistic and has been further developed in more recent years. Meeuwisse et al[58] and Bittencourt et al[7] contend that the ability to predict and prevent athletic injury remains limited as researchers continue to apply a static, linear approach to a dynamic, complex problem. Meeuwisse first recognized the multifactorial nature of the etiology of injury and further refined the model with the Dynamic Recursive Model of Etiology in Sport Injury (Figure 2).

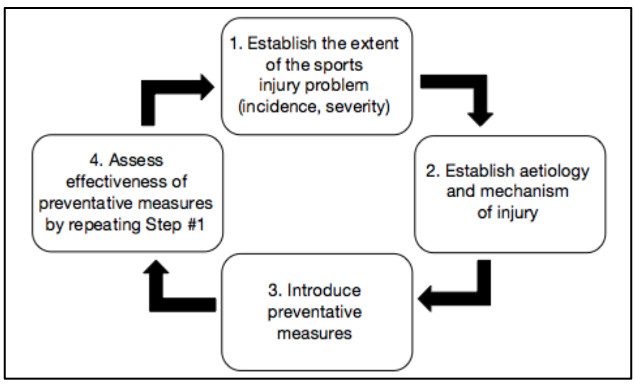


Figure 1 Van Mechelen's "Sequence of Prevention" (Adapted) (Van Mechelen et al., 1987; Van Mechelen et al., 1992)

Fluctuations in physical measures such as range of motion and strength across a season are likely to result in fluctuating risk.[40] For example, both Reinold et al[75] and Freehill et al[33] found that glenohumeral range of motion changed after a single bout of throwing, and Freehill et al[33], Laudner et al[50], and Shanley et al[85] reported changes in range of motion cumulatively across one or more seasons. Additionally, Bittencourt et al[7] proposed that risk factors continuously interact to dynamically alter risk of athletic injury over time. McHugh et al[56] found that in high school pitchers, supraspinatus strength decreases during the season, and this was particularly the case for high volume pitchers (13% loss). These examples lend credence to the idea that a pitcher who does not present with a particular risk factor in the preseason may acquire that risk during the season. Yet, all prospective studies of baseball injury risk have relied only on preseason measurement, and only one addressed the problem of a recent throwing bout.[81] These changes support the notion that risk attributed to factors that vary during the season will also vary, and therefore the observation of multiple time points to reflect that changing risk is necessary. To date, assessment of physical characteristics related to injury risk in baseball pitchers has been narrowly focused and has failed to consider the dynamic nature of musculoskeletal injury risk and prevention. Therefore, I propose an adaptation to the dynamic, recursive model to tailor it to pitching-related shoulder and elbow injuries taking into account the multifactorial, dynamic nature and interaction among and between intrinsic and extrinsic risk factors (Figure 5).

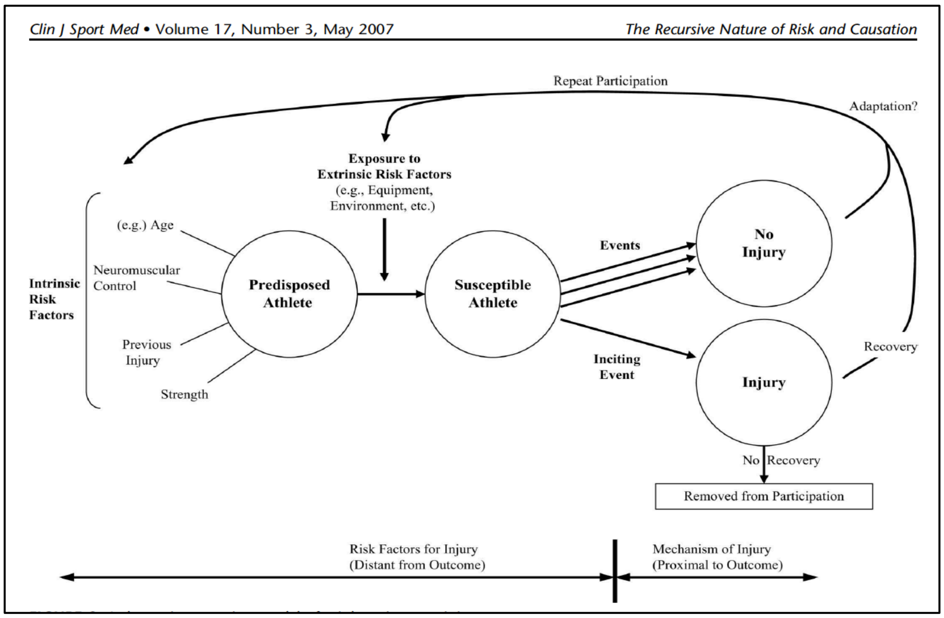


Figure 4. Meeuwisse's "Dynamic, Recursive Model of Etiology in Sport Injury" (Meeuwisse et al., 2007)

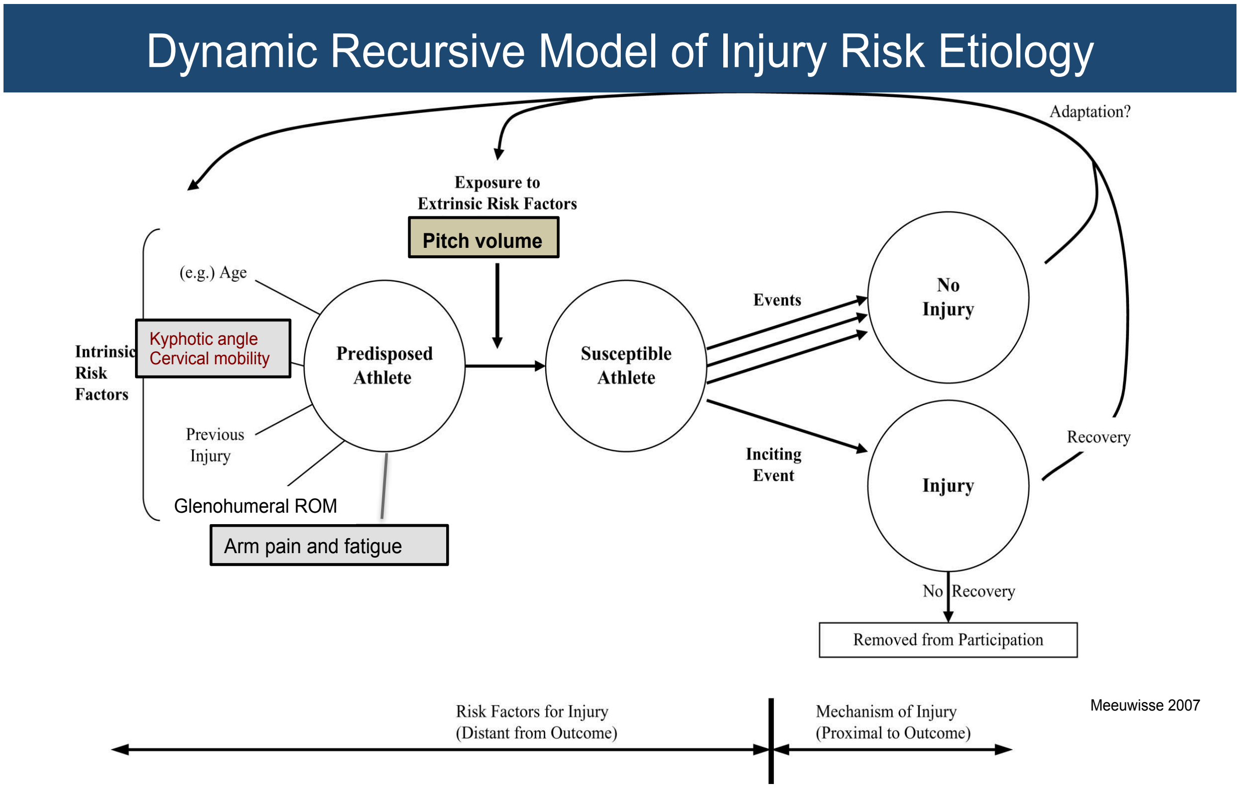


Figure 5. Dynamic Recursive Model Adapted for Pitching Related Shoulder and Elbow Injury

Prevention

In the study of baseball injury prevention, research is largely still in Stage 2 of the TRIPP model as some important risk factors have not been thoroughly explored and has just begun to venture into the development of prevention programs. Two prospective study have examined the efficacy of a prevention program aimed at reducing elbow injury.[79,88] Shitara et al[88] studied a cohort of high school baseball players and found that a targeted stretching program based on prior prospective research identifying range of motion and strength impairments as risk factors for injury resulted in decreased injury risk across a season. This was a promising first step toward prevention, but the researchers only addressed risk factors at the shoulder, and measurement of risk factors was limited to preseason. More recently, a well-designed study by Sakata et al[79] demonstrated the efficacy of a stretching and strengthening program in youth pitchers in altering physical risk factors and reducing medial elbow injury rates. The program addressed known risk factors including shoulder range of motion and strength, hip and trunk range of motion, core stability, balance, and posture. The incidence rate was significantly lower in the treatment group (0.8/1000 athlete-exposures) than the control group (1.7/1000 athlete-exposures) (hazard ratio, 50.8%; 95% CI, 0.292-0.882; P = .016).[79] While prior studies have been able to demonstrate improvements in risk factors following interventions such as manual therapy[5], stretching[5,12], and strengthening exercises, these are the first trials to establish that a prevention program can reduce injury rates.

Summary of Literature Review

Researchers have identified a number of physical factors that increase risk of throwing-related shoulder and elbow injury in baseball players, but the model is incomplete with a number of plausible factors yet to be explored. Pitch volume and glenohumeral ROM appear to be the strongest risk factors at certain age and competition levels, but risk factors vary across age and competition levels, and it is likely that each competition level identifies a unique risk profile. Thus, the goal of the proposed research is expected to be identification of novel risk factors for throwing-related shoulder and elbow injury that will improve understanding of the mechanisms of shoulder and elbow pain and will aid in the development of strategies to prevent these injuries.

CHAPTER II: INTRODUCTION

The drastic increase in serious throwing-related shoulder and elbow injuries in baseball has led to increased focus on research and application of injury prevention programs. Evidence based prevention programs can effectively reduce musculoskeletal injury rates in athletes as evidenced by the reduced lower extremity injury rates in athletes using programs such as the FIFA11+.[89] Current practices aimed at prevention of throwing-related shoulder and elbow injuries in pitchers include pitch count and rest mandates, but robust, evidence based prevention programs are in the development stage . Identification of important risk factors is central to development of effective prevention programs[3], but study of intrinsic risk factors such as range of motion and strength have been largely limited to the shoulder. [6,24,46-7,54,60-1] Additionally, most injury research in baseball players only views injury through frequency and time loss statistics. Few authors have examined non-time-loss metrics as outcomes in addition to time-loss, and collectively, the incomplete picture of the burden of injury on baseball pitchers presents a barrier to prevention.[44,54] In the meantime, throwing-related upper extremity injury is anticipated to increase over the next decade,[32] and failure to identify important risk factors, expand the definition of injury as an outcome, and recognize the changing nature of risk during the season will impede development of a sound strategy for prevention.

Efficient pitching depends on effective load transfer across the kinetic chain, yet study of other regions beyond the shoulder and the potential influence on upper extremity injury risk has only recently gained Interest.[25,35] Given the anatomical and functional relationships of the spine and shoulder, the role of the neck and thoracic region as risk factors shoulder be investigated. There is emerging evidence for the importance of adequate strength and motion of the lumbar and thoracic spine in throwers.[11,78] In 1986, Young et.al proposed that the cervical spine may play a role in glenohumeral pathology for overhead throwers due to anatomical relationships and it's role in target acquisition and force generation.[104] Since then, the role of the cervical and thoracic spine has been ignored despite the relationship between cervicothoracic dysfunction and upper extremity conditions.[3,8,60,66] For example, increased thoracic kyphosis and accompanying stiffness limit shoulder elevation and abduction, alter scapular posture, and contribute to scapular dyskinesis, which has been identified as a risk factor for arm injury.[24,41] In turn, forward scapular posture is associated with posterior shoulder tightness in baseball players.[51] This is consistent with research indicating a relationship between increased kyphosis and subacromial shoulder pain, a common complaint in pitchers.[65] Further support comes from evidence of reduced pain and increased shoulder mobility in patients with primary shoulder pain following spinal manipulation.[59,88] It stands to reason that limited spinal mobility could lead to changes in upper extremity kinematics in pitchers that may put them at risk for injury. Recently, Sakata et al[78] reported that youth baseball players with a spinal kyphosis measure of greater than the sample mean (30°) had 2.5 times greater odds of medial elbow injury (OR 2.50 (95%CI 1.381-4.531). To date, physical measures of the cervical spine have not been reported in baseball players, and there are no studies examining a possible relationship with throwing-related injury.

The central hypothesis of this proposal is that spinal kyphosis and neck mobility are important physical characteristics that can impair upper extremity function and lead to injury in overhead athletes. Preliminary data on a cohort of college baseball players suggests that increased kyphosis and reduced upper cervical rotation mobility increase the risk of injury in players to a greater extent than other known physical risk factors. A dynamic risk profile for modifiable risk factors that incorporates body regions beyond the upper extremity would enhance the ability to stratify athletes by risk across the entirety of the season and test interventions aimed at prevention. Thus, the *overall objective* of this study is to estimate the risk of shoulder and elbow injury attributed to impaired posture and limited neck mobility in relation to known risk factors in college baseball pitchers and to assess the dynamic nature of this risk.

Research Question 1

Preliminary data from my prospective study of a small cohort of Division 1 collegiate baseball players found that spinal kyphosis and upper cervical rotation mobility were important predictors of throwing-related shoulder and elbow pain and disability.[14] The Cervical Flexion Rotation Test (FRT) measures upper cervical rotation mobility, and it accounted for 20% of the variance (R^2=.20. p=.011) in pain and disability as measured by the DASH-SM. In clinical terms, if a player had less than 38° on the dominant side FRT, he had 15 times the risk of shoulder or elbow pain and disability versus a player with more than 38° (95% CI 0.87-555.00). Dorsal kyphosis (Inclinometric Kyphosis Measure-IKM) accounted for 12.4% of the variance, (R^2=12.4, p=.029), and a measurement of less than 143° was associated with 7.55 times increased risk of reporting arm pain and disability during the season (95% CI .78-117.00). In other words, the more kyphotic the player, the more likely he was to report pain and disability. Interpretation of risk was limited by the restricted sample and wide confidence intervals, and the analysis was limited to non-time-loss data. In the proposed study, a focus on pitchers, increase in sample size, inclusion of non-modifiable variables in the regression analysis, and analysis of both time-loss and non-time-loss injury should result in narrower confidence intervals for the risk estimates and an expanded picture of injury risk. Therefore, I believe this data supports the underlying concept and feasibility of the proposal.

Research Question: Does impaired posture and limited cervical mobility increase the risk of shoulder and elbow pain, disability, and injury in college baseball pitchers?

Hypothesis: Increased dorsal kyphosis and limited upper cervical mobility increase the risk of developing shoulder and elbow pain, disability, and injury in college baseball pitchers.

Independent Variables of Interest:

- Inclinometric Kyphosis Measure
- Cervical Flexion Rotation Test
- Cervical Active Range of Motion

Dependent Variables:

- Disabilities of the Shoulder, Arm, and Hand Sports Module
- Functional Arm Scale for Throwers
- Time loss (secondary to shoulder or elbow pain)

Research Question 2

Research Question: Do physical risk factors change during the course of the season and does the associated risk attributed to those factors also change across the baseball season?

Hypothesis: Physical measures change during the course of the season and associated risk of throwing-related shoulder and elbow pain, disability, and injury attributed to those measures similarly changes across the season.

Independent Variables:

- Inclinometric Kyphosis Measure
- Cervical Flexion Rotation Test
- Cervical Active Range of Motion

Dependent Variables:

- Disabilities of the Shoulder, Arm, and Hand Sports Module
- Functional Arm Scale for Throwers
- Time loss (secondary to shoulder or elbow pain)

Limitations

In prospective studies, there is uncertainty surrounding injury incidence and this can have a significant effect on the results of the study. For this reason, we selected pitchers as they typically have a higher injury incidence than position players. The sample size is adequate for the primary research question, but admittedly, depending on distribution of data, injury incidence, and attrition, it may be underpowered to detect group differences and relationships with regards to the secondary research questions.

Based on our preliminary data and considering the exploratory nature of the proposal, we expect to find associations and adequately analyze the variance due to the 2 primary risk factors of interest. Additionally, Sensitivity and Specificity are not influenced by incidence, so in the case of low incidence, the diagnostic utility can still be interpreted. That said, the primary limitation of the study is the sample size for the final analysis, and therefore, these results should be interpreted cautiously with respect to generalizability.

Accurate tracking of time-loss and non-time loss outcomes is also a concern. Participants will complete the patient reported outcomes weekly on the same day of the week (Tuesday) in an attempt to control for the effect of the baseball schedule and minimize recall bias. This may be affected by schedule changes due to inclement weather. The research team will periodically meet with the Head Athletic Trainer of each team to confirm accuracy of pitch counts and time-loss data, and members of the research team will communicate with participants every other week during the season to facilitate compliance with patient-reported outcome tools. Our analyses will use an average score for each subjective outcome that should allow for a threshold of 20% missing weekly data in assessing injury risk. In addition, the use of both time-loss and non-time-loss outcome measures allows us flexibility should we have incomplete data in any one area.

Participants may also underreport pain due to fear of losing playing time, and this may affect our non-time-loss data. Participants will be made aware that baseball staff will NOT have access to non-time-loss data, which should abridge this concern.

Delimitations

The status quo as it relates to injury prediction in baseball is a static model that relies on preseason screening of upper extremity physical measures and a definition of injury that consists primarily of time-loss. Prior research has provided components of the model, but the current approach impedes the development of a clinically useful prediction model for throwing-related upper extremity injury in baseball players. In order to optimally predict which pitchers are likely to develop throwing-related arm injury and develop interventions, the contribution of all important risk factors must be estimated.[3,25] In addition, the results of screening studies must be appropriately interpreted through a clinical lens, and the dynamic nature of these results must be acknowledged. To this end, calculation of predictive values and risk ratios with interpretation of credible intervals for post-test values and use of multidimensional patient oriented outcomes would provide more clinically meaningful information for prevention of throwing-related arm injury in pitchers*. The strengths of the proposed research are that it expands on the realm of potential risk factors (posture and neck mobility) that have not been considered in prior studies, frames throwing-related injury in a new light in terms of important, patient reported outcomes other than time-loss, and explores baseball injury risk as a dynamic variable.* The analytic strategy included diagnostic efficacy calculations and interpretation of confidence intervals to allow for a more realistic understanding of the clinical utility of these factors in predicting injury risk with respect to level of certainty. This overall strategy provides a better picture of the burden of both time loss and non-time loss injuries on college baseball pitchers, expands on the data regarding physical predictors of risk, and will better inform health care providers and researchers alike as to targeted interventions that prevent overuse type injuries.

CHAPTER III: METHODS

Design

This is a prospective study of the relationship between spinal mobility measures and risk of shoulder and elbow pain, disability, and injury in college baseball pitchers. The overall approach will be to measure selected physical characteristics during preseason, and then track upper extremity injury and patient reported outcomes over the course of a college baseball season.

Participants

The participants will be male college baseball pitchers age 18-23 years old who play are medically cleared to play baseball at UConn, Eastern Connecticut State University (ECSU), and Sacred Heart University (SHU). Those younger than 18 and those with a current injury precluding participation in baseball activities will be excluded. Participants will be enrolled without regard to ethnicity or income.

Examiners

The examiners are licensed physical therapists, licensed certified athletic trainers, graduate students in the UCONN Doctor of Physical Therapy Program, or undergraduate students enrolled in the UCONN Athletic Training or Exercise Science curriculum. The licensed examiners and DPT students are competent in performance of the physical measures. All examiners will participate in a training session to standardize the measures, improve consistency, identify the most consistent and accurate examiner for each measure, and plan the data collection strategy for optimal efficiency and accuracy.

Location

Data collection will be conducted at the following locations for purposes of privacy and convenience for participants:

UConn: Burton Athletic Facility Training Room

ECSU: ECSU Sports Center Athletic Training Room and Club Sports Room

SHU: William H. Pitt Health and Recreation Center

Methods

Research Question 1

Recruitment and informed consent will take place during early preseason (January 2018). Within the first two weeks of preseason, participants who are enrolled will complete an intake questionnaire, baseline patient reported outcome measures, and physical measures testing as described below. During the season, participants will complete a weekly pain and disability questionnaire and self-assign as “playing without pain, playing with pain, or not playing due to pain”. The Head Athletic Trainer will track time loss to shoulder or elbow injury, and pitch counts will be obtained from the coaching staff.

Research Question 2

Patient reported outcomes and physical measures will be repeated during a mid-season testing session between March 19 and April 13. Differences in physical measures between the two time points will be analyzed, and the change in risk associated with these changes will be assessed.

Recruitment and Enrollment

We will screen 60-70 male, college baseball pitchers. Based on the results of our preliminary study, we anticipate that less than 5 participants will fail screening, and expect approximately 10% attrition for the final analysis. Participants will be screened for eligibility at the time of consent. Participants will be asked their age and whether they are medically cleared to play baseball. Those who are younger than 18 or who are not medically cleared to play baseball will not be enrolled.

Preseason

Intake Questionnaire: The Intake Questionnaire will gather information regarding participants' shoulder and elbow injury history, pitching history, and status over the past year (Playing with Pain, Playing Without Pain, Unable to Play Due to Pain.)

Demographics: Participant age, height and weight will be measured and lateral preference will be assessed with the Lateral Preference Inventory.[19] Several authors have found differences in physical characteristics and pitching mechanics between right and left handed pitchers, and this should be considered as a potential confounder.[90,96]

Measurement of Kyphosis:

The Inclinometric Kyphosis Measure (IKM) is a reliable and valid measure of spinal kyphosis.[20] For this project, the Microfet3 Digital Inclinometer will be used to obtain the IKM.

Each participant will be measured in usual posture (relaxed) and best posture (cued). The participant stands with the anterior thighs lightly contacting a treatment table with shirt removed. The participant will be instructed to stand still and look straight ahead. Ultrasound gel will be applied to the midline of the lower thoracic and lumbar spine and to the upper thoracic spine to facilitate glide of the inclinometer so that the therapist is able to maintain contact with the skin while moving the inclinometer. The examiner zeroes the inclinometer prior to measuring the relaxed and cued positions. The examiner first aligns the inclinometer vertically along the lower lumbar spinous processes. (Figure 1). While maintaining light contact with the skin, the examiner then moves the inclinometer superiorly along the spine until the curve first reverses and records the angle in degrees (TL). The inclinometer is then aligned vertically along the upper mid-thoracic spinous processes . While maintaining light contact with the skin, the examiner then moves the inclinometer superiorly along the spine until the curve first reverses and records the angle in degrees (CT). The two recorded angles are added together and their sum subtracted from 180° to arrive at a measure of the dorsal kyphosis (IKM°= 180°-(TL° + CT°). The examiner then verbally instructs the participant to stand as straight and tall as possible and repeats the measurement for the cued measurement.

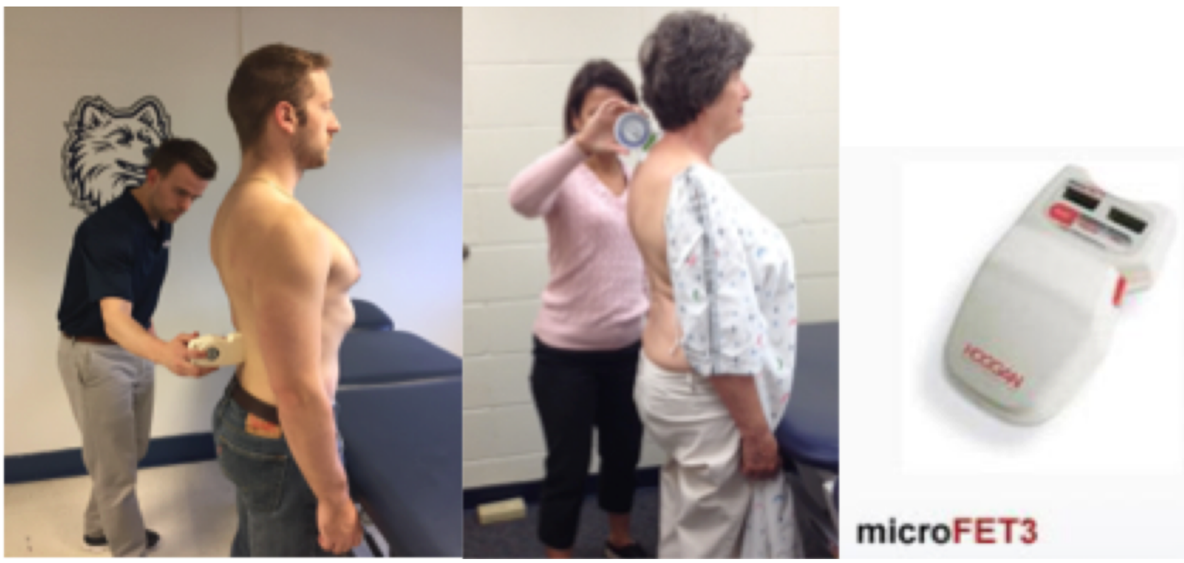


Figure 1. Inclinometric Kyphosis Measure

Mean scores for the relaxed condition range from 124.1° +10.8 in an outpatient orthopedic population[20] to 130.7° + 4.6 in healthy adults aged 18-73 (Devaney LL unpublished data 2017). In the cued condition,132.0° in orthopedic patients[20], and 143.6° in our preliminary study of 33 baseball players (Devaney LL unpublished data, 2016). Intra-rater reliability of the IKM has been demonstrated in healthy adults (ICC .98 (.94-.99), SEM= 1.28°, MDC= 3.55°) (Devaney LL et al,unpublished data 2017), and in patients with orthopedic conditions in an outpatient setting[20] ($ICC_{relaxed}$= .94 (.89-.96), SEM 8°); ICC_{cued}=.91 (.84-.95), SEM of 10°) (Devaney LL unpublished data, 2016).

According to prior work by this investigator, a strong correlation exists between the IKM and the reference standard Cobb angle measurement (r=.72 ; 95% CI .36-.1.08, p=.001.[20]

Measurement of Cervical Mobility

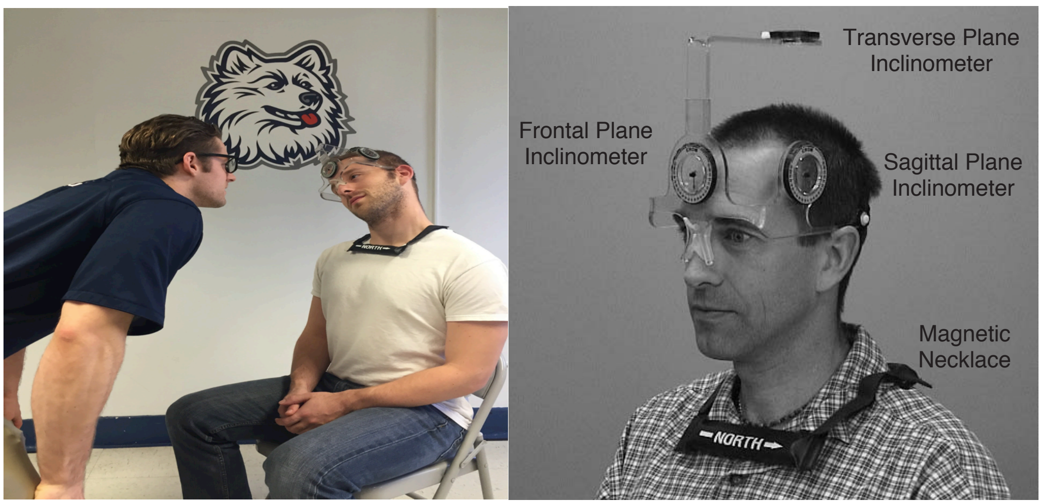


Figure 2. Cervical Active Range of Motion

1. <u>Cervical Active Range of Motion   (CAROM)</u>: Cervical AROM in flexion and extension, right/left lateral flexion, and right/left rotation will be measured for each participant using the CROM® device (Figure 2). Prior to measurement, the examiner will demonstrate the 6 cervical motions to be performed. To minimize variability in measurement caused by differences in the subject's body and head position, each subject will sit in a straight-back chair with upright posture, low and mid back regions contacting the backrest, feet flat on the floor, and upper extremities positioned at the sides with the shoulders relaxed. Participants will be cued to maintain contact with the backrest to minimize substitution from the trunk. Each subject will perform two repetitions of each motion through a comfortable yet complete AROM to ensure subject familiarity. The examiner will cue the participant so that the subject's nose, chin, and visual gaze are pointing straight ahead

with the eyes horizontally level. For all measurements, the relevant inclinometer will be read to the nearest 1°. With any of the cervical movements, if a subject does not follow the tester's instructions correctly, the measurement will not be taken, instructions will be repeated, and the movement repeated and recorded. Following the reading of each measurement, the tester will move the participant back to the starting position before performing the next measurement. The CROM® is reliable with an ICC of .93-.98 with an SEM of 1.6° to 2.8° and the MDC across the 6 movements of 3.6° to 6.5°.[4]

2. <u>Cervical Flexion-Rotation Test (CFRT):</u>

Figure 3. Cervical Flexion Rotation Test

The Cervical Flexion-Rotation Test (CFRT) measures segmental mobility in rotation of the upper cervical spine (Figure 3). The CFRT is conducted with the subject relaxed and recumbent. The cervical spine is fully flexed with the occiput resting against the examiner's abdomen, and the CROM® is used to measure cervical rotation in a fully flexed cervical spine position. The examiner rotates the head to the left and right and a second examiner records the goniometric measure. Mean range of motion has been reported to be 39-45° in healthy adults with an SEM of 2-3° and MDC of 4.7-7°.[8]

Glenohumeral Passive Range of Motion (GH PROM):

Figure 4. Glenohumeral Passive Range of Motion

Each pitcher will be measured for flexion, external and internal shoulder rotation, and horizontal adduction passive range of motion (PROM) of both shoulders using a Microfet3 digital inclinometer (Figure 4). Examiners will be blinded to hand dominance, and the primary examiner and participant will be blinded to performance results. Two trials will be taken for each motion with the average used for analysis.

Internal/External Rotation: GH PROM testing will be performed with the participant in supine with the upper arm positioned on a towel roll at 90° abduction and 90° elbow flexion. The examiner will stabilize the glenohumeral joint by placing four fingers on the scapula and the thumb of one hand on the anterior aspect of the shoulder over the clavicle, coracoid process, and humeral head as described by Wilk et al.[101] The examiner will move the participant's arm through a full arc of motion until an end point is reached. End of motion is defined as a cease of motion or when scapular movement is perceived as the coracoid moves into the examiner's hand. A second examiner will position the inclinometer and record the end-point shoulder angle.

Flexion: Flexion will be assessed with the subject lying in supine with hips and knees flexed. The tester will flex the subject's shoulder at the glenohumeral joint while stabilizing the lateral border of the scapula to prevent posterior tilt and upward rotation. A second examiner will position the inclinometer along the humerus and record the end-point shoulder angle.

Horizontal adduction: Horizontal adduction will be measured as described by Shanley et al[83]. With the participant in the supine position, the examiner stabilizes the scapula in a retracted position with the thenar eminence contacting the lateral aspect of the scapula. The examiner passively horizontally adducts the arm and finds the end of motion defined as a cease of motion or when scapular movement is perceived as the scapula moves into the examiner's hand. A second examiner measures the angle between the humerus and the horizontal plane. Reliability of inclinometer measurement at the shoulder is excellent with an ICC for intra-rater reliability of .97 and .98, respectively, and an SEM of 2°.[18]

Outcome Measures: The outcome measures included in this study were selected to capture patient-oriented outcomes that include both time-loss and non-time-loss components. All NTL measures have demonstrated sound psychometric properties in identifying pain, disability, or health related quality of life in individuals with upper extremity conditions.

Time-loss: Time-loss injury will be recorded as any athlete exposure (practice or game) missed due to shoulder or elbow complaints. This information is collected as part of routine practice and will be provided by the Head Athletic Trainer at each baseball program. Additionally, we will calculate the number of injuries per 1000 pitches as this may be a better indicator of injury risk in pitchers. On Monday of each week during the season, a member of the research team will confirm accuracy of time-loss data with the

Head Athletic Trainer of each program.

Non-time-loss: The Head Athletic Trainer of each baseball program will provide information on athletes who were evaluated or treated by the AT or physician for shoulder or elbow pain but were restricted from participation beyond the day of injury. Additionally, the Disabilities of the Shoulder, Elbow and Hand Score (DASH) and Functional Arm Scale for Throwers (FAST) are patient-reported outcomes that will be completed at baseline by the participants.

The DASH is a region specific patient-reported outcome that measures upper extremity symptoms and disability. The 4-item DASH Sports Module captures an individual's level of disability in playing his or her sport. The lower the score on the DASH-SM, the better the score. While there is significant evidence that the DASH is a reliable, responsive, and valid measure in patients with shoulder or upper limb problems, the DASH doesn't target the shoulder and elbow specifically and is not sport specific.[3] However, Radwan et al demonstrated a strong negative correlation between the Kerlan Jobe Orthopedic Clinic Shoulder and Elbow Score and DASH-SM ($r = -.825$, $p = .01$)[72]

The FAST is a region specific and baseball specific outcome tool that consists of 22 items and a 9-item pitcher module that may be interpreted independently.[81] The FAST is reliable, valid, and responsive and is able to discriminate between injured and uninjured players.[43] For predicting upper extremity injury status, a FAST total cutoff score of 10.0 out of 100.0 was 91% sensitive and 75% specific, and a pitcher module score of 10.0 out of 100.0 was 87% sensitive and 78% specific.[43]

During the season, patient reported outcomes will be collected using an SMS Qualtrics software survey sent to each participant. Players will complete the DASH-SM every week, and FAST-PM biweekly to measure *pain* and *disability*.

Midseason

All physical measures (including height and weight) and outcome measures will be collected as described in the prior section at a second testing session scheduled during midseason at approximately 9-10 weeks into the season.

Data Reduction & Statistical Analyses

Based on an (α) level of .05, power= .80, and correlation coefficient between the IKM and injury risk of r=.448 from preliminary data, the required sample size for the primary aim is 37 (www.statstodo.com). Given uncertainty surrounding injury incidence, wide confidence intervals in the preliminary study, and an assumption of 10% attrition, a sample size in the range of 50-60 should be adequate for analysis with increased precision of risk estimates. This is consistent with recommendations from Flauhault et al[30] based on an expected Sn of .89 and minimal acceptable lower confidence limit of .70 which would indicate a sample size of 41 for diagnostic test studies.

We will compare all measures between injured and uninjured groups using a MANOVA. Measures that differ between groups will be used to produce ROC curves to derive Sensitivity, Specificity, and cutoff values. Participants will be dichotomized into “positive” and “negative” for the tests based on cutoff values, and Positive and Negative Predictive values and risk ratios will be computed. We will then calculate confidence intervals around the risk estimates to get a candid and realistic interpretation of the clinical meaning of these values in predicting injury.

To answer Research Question 2, change scores will be calculated for each physical measure, and MANOVA and graphical interpretation will be used to assess significance and explore patterns of change, respectively. Change scores will be entered into the same multiple multivariate regression model,ROC curves will be generated using data from the midseason analysis, and risk estimates between the preseason and midseason will be compared. Specifically, the following will be performed:

The following data analyses will be performed using SPSS software:

- Descriptive statistics (mean, standard deviation) will be calculated.
- Injury incidence will be reported as injury/1000 pitches.
- Correlations between physical measures and pain, disability, and injury will be calculated using Pearson Correlation Coefficient (assuming data is normally distributed).
- Linear regression will be conducted to estimate the variance in interval outcome measures
- ROC Curves will be created to calculate Sensitivity, Specificity, Cutoff scores, Likelihood ratios, Negative and Positive predictive values, and risk ratios.
- Groups will be dichotomotized according to cutoff scores for risk factors and logistic regression will be used to assess usefulness of each factor or a combination of factors as a screening tool
- Change scores will be calculated for each measure from preseason to mid-season. ANOVA and graphical interpretation will be used to assess significance and explore patterns of change.
- Change scores will be entered into a linear regression model with known risk factors (Prior injury, pitch volume). ROC curves will be generated and using data from the midseason collection, and risk estimates between the preseason and mid-season will be compared.

CHAPTER IV

Preseason Neck Mobility Predicts Throwing-related Shoulder and Elbow Pain and Disability in College Baseball Pitchers

Research Question: Does impaired posture and limited cervical mobility increase the risk of shoulder and elbow pain, disability, and injury in college baseball pitchers?

Target Journal: American Journal of Sports Medicine

ABSTRACT

Background: Shoulder and elbow injuries in baseball pitchers have been on the rise for three decades at all levels of play and result in significant pain and disability. Despite anatomical and neural relationships, neck mobility impairments have not been explored as contributors to shoulder and elbow injury. **Purpose**: To investigate the role of cervical/thoracic mobility as predictors of shoulder and elbow pain and disability in college baseball pitchers. **Design**: Cohort study. **Methods:** Forty-nine healthy college baseball pitchers (19.92 ±1.48 years, 187.04 ±6.02 cm, 89.14 ± 12.08 kg) were enrolled prior to the 2018 college season. Posture, neck mobility, and glenohumeral passive range of motion were measured during preseason using the Inclinometric Kyphosis Measure, CROM®, and inclinometer, respectively. Time-loss (days lost to shoulder or elbow injury) was recorded, and patient reported disability was captured using the Disabilities of the Arm, Shoulder, and Hand Sports Module (DASHSM) and the Functional Arm Scale for Throwers (FAST). Pitchers were dichotomized into Injured and Uninjured groups based on time-loss and cutoff scores for patient reported outcomes. Differences between Injured and Uninjured groups were analyzed with the Mann-Whitney U test. Receiver Operating Characteristic curves were generated, and diagnostic accuracy values and risk ratios (RR) were calculated to assess the predictive utility of the physical measures. **Results**: Ten pitchers (20.4%) sustained a time-loss injury (> 7 days) due to shoulder or elbow injury. A dominant side Cervical Flexion Rotation Test of <39° resulted in over 9 times increased risk of time-loss injury (RR=9.38, 95%CI 1.28-68.49). Dominant side Cervical Flexion Rotation Test of <39°, Cervical Flexion Range of Motion < 64°, and mass >86.86 kg were also associated with increased risk of patient reported pain and disability on the FAST Pitcher Module ((RR=4.05, 95%CI 1.02-16.04, RR=8.90, 95% CI 1.27-62.26 and RR=10.42, 95%CI 1.14-213.70, respectively). **Conclusions**: College baseball pitchers with less neck mobility during preseason had increased risk of both time-loss and patient reported shoulder and elbow pain and disability. Diagnostic utility of these screening measures as part of a risk profile should be further explored.

Key terms: Cervical spine, injury prevention, injury risk,

Word count: 335

INTRODUCTION

The incidence of upper extremity injury in baseball players has been on the rise for the past three decades at all levels of play.[9,15,21] In college baseball players, 45% of injuries between 1988-2015 occurred in the shoulder and elbow,[21,54] and pitching was associated with 73% of these injuries.[21] These injuries often result in significant disability and account for as much as 75% of time lost in college baseball players.[54] In Major League Baseball from 1998-2015, shoulder and elbow injuries accounted for 54.5% of time on the disabled list, and in 2015 alone, they led to over 16,000 days missed.[17] Most concerning, however, is the persistent increase in serious injury in younger pitchers with a recent review predicting that in the next decade, the average annual incidence of ulnar collateral ligament injury due to throwing in males age 15-19 will double from 6.3 per 100,000 to 14.6 per 100,000.[56] The authors noted a disturbing trend of an average annual increase in number of UCL-R performed of 18%, cumulative increase of 343% over 10 years, and subsequent decrease in average age at surgery from 20.5 to 19.1 years. [56]

Current practices aimed at throwing-related injury prevention in baseball include pitch count and days-of-rest restrictions, but comprehensive, evidence based prevention programs are in the development stage. Identification of important risk factors is central to development of effective injury prevention programs.[3] Factors such as exposure (i.e. pitch volume[18,21,46]), arm fatigue,[37,64] poor pitching mechanics,[7] and physical characteristics such as humeral torsion,[63] reduced glenohumeral range of motion,[6,24,46,47,54,59,60] rotator cuff weakness,[24,54,56] and altered scapular kinematics.[26] may increase risk of sustaining a throwing-related shoulder or elbow injury among baseball pitchers. Study of intrinsic risk factors, however, has primarily targeted shoulder anatomy and impairments. [6,24,46-7,54,59,60] Since pitchers depend on effective load transfer across the kinetic chain to optimize efficiency and performance, other body regions beyond the shoulder should be considered with respect to injury risk.[25,35]

Given the anatomical and functional relationships between the spine and upper extremity, the cervical and thoracic regions are reasonable targets for investigation.[11,76] In 1986, Young et al[104] proposed that the cervical spine may play a role in glenohumeral pathology for overhead throwers due to anatomical relationships and it's role in target acquisition and force generation.[104] This is consistent with research demonstrating a relationship between cervicothoracic dysfunction and painful upper extremity conditions such as subacromial impingement syndrome.[3,8,26, 59,64 65] Furthermore, there is evidence of reduced pain and increased shoulder mobility following spinal manipulation in patients with primary shoulder pain.[59,88] Recently, Sakata et al[76] reported that youth baseball players with a kyphosis measure of greater than 30° had 2.5 times greater odds of medial elbow injury (OR 2.50; 95%CI 1.38-4.53). This lends credence to the notion that spinal mobility impairments may contribute to shoulder and elbow problems in throwing athletes;

Most authors of prospective research into baseball injury risk have focused on time-loss (TL) injuries, which are typically defined as "injuries that restrict the athlete's participation for at least 24 hours beyond the report of injury."[48] However, numerous studies have demonstrated that a high percentage of baseball pitchers continue to pitch with arm pain.[52, 62] This suggests that only measuring TL presents an incomplete picture of disability attributed to shoulder and elbow injury, and the addition of patient reported outcomes could help to close that gap.

To date, physical measures of cervical spine mobility and potential relationships with throwing-related injury have not been examined in baseball players. Additionally, the limited definition of injury through TL does not comprehensively measure the burden of injury experienced by baseball pitchers. The purpose of this study was to prospectively investigate the predictive value of measures of neck mobility and posture in the development of shoulder and elbow pain and disability in college baseball pitchers across a season quantified by both time-loss and patient-reported outcome.

METHODS

This was a prospective study conducted across a single college baseball season. The University of Connecticut Institutional Review Board approved the human subjects protocol prior to participant recruitment.

Participants

Pitchers were recruited from two NCAA Division 1 and one NCAA Division 3 college baseball teams in January 2018 and were screened for eligibility at the time of consent. To be eligible, pitchers had to be age 18 years or older and medically cleared to participate in baseball activities. Pitchers were excluded from the study if they were younger than 18 or had a current shoulder or elbow injury which precluded participation in baseball activities. Based on an α level of .05, power= .80, and a correlation coefficient of r=.448 from preliminary data, the required sample size was 37 (MedCalc for Windows, version 17.0 (MedCalc Software, Ostend, Belgium). This was consistent with recommendations from Flauhault et al[30] based on an expected sensitivity of .89 and minimal acceptable lower confidence limit of .70 which indicated a sample size of 41 for diagnostic accuracy studies.

Examiners

A licensed physical therapist/athletic trainer and four trained graduate Doctor of Physical Therapy students collected all physical measures and patient reported outcomes. The same rater performed all measures at each testing session. The team athletic trainers collected time-loss and pitch count data, and they did not have access to the pitchers' patient reported outcomes during the season.

Data collection

During early preseason, pitchers completed an intake questionnaire and baseline patient reported outcome measures. The Intake Questionnaire gathered information regarding age, hand dominance, shoulder and elbow injury history, months pitched in 2017, and playing status in 2017 (Playing with Pain, Playing Without Pain, Unable to Play Due to Pain). Posture, neck mobility, and bilateral glenohumeral passive range of motion were measured as described below. Measurements took place on a day when players had not pitched within the past three days to account for acute changes in mobility secondary to throwing. Throughout the season, participants completed a weekly online questionnaire to assess pain and disability, and the team athletic trainer tracked time-loss and game and bullpen pitch counts.

Physical Measures

The Inclinometric Kyphosis Measure (IKM) is a reliable and valid clinical measure of posture.[20] Each pitcher was measured in both usual posture (relaxed) and best posture (cued) using the Microfet3 digital inclinometer (Hoggan Scientific, Salt Lake City, UT) as outlined in Devaney et al.[20-2] In relaxed posture, the examiner first aligned the inclinometer vertically along the lower lumbar spinous processes to measure the thoracolumbar angle. (Figure 1a). The inclinometer was then aligned vertically along the upper mid-thoracic spinous processes to measure the cervicothoracic angle (Figure 1b). The two recorded angles were added together, and their sum was subtracted from 180° to arrive at a measure of dorsal kyphosis. Two trials were performed and the mean measure was recorded. The examiner then instructed the pitcher to “stand straight and tall” and repeated the measurement for the cued condition.

Figure 1a. Inclinometric Kyphosis Measure (Thoracolumbar angle). While maintaining light contact with the skin, the examiner moved the inclinometer superiorly along the spine until the curve first reversed and recorded the angle in degrees.

Figure 1b. **Inclinometric Kyphosis Measure (Cervicothoracic angle).** While maintaining light contact with the skin, the examiner then moved the inclinometer superiorly along the spine until the curve first reversed and recorded the angle in degrees.

Intra-rater reliability of the IKM has been demonstrated in healthy adults (Devaney et al unpublished data, 2017) ($ICC_{3,1}$= .98 (.94-.99), SEM= 1.28°, MDC= 3.55°) and in patients with orthopedic conditions in both the relaxed ($ICC_{3,1}$= .94 (.89-.96), SEM=3°, MDC=8°) and cued conditions ($ICC_{3,1}$=.91 (.84-.95), SEM=3°, MDC=10°).[20]

Cervical Active Range of Motion (CAROM) was measured in six directions (flexion, extension, right/left lateral flexion, and right/left rotation) with the CROM® device (Performance Attainment Associates, Roseville, MN) as described by Audette et al[4]

(Figure 2a). Prior to measurement, the examiner demonstrated the 6 cervical motions to be performed, and participants performed a familiarization trial of each motion. Each participant then performed two trials of each motion through a comfortable yet complete range, and the mean of the two scores was recorded. The CROM® is reliable across the 6 movements with an ICC =.93-.98, SEM =1.6°-2.8°, and MDC=3.6°-6.5°.[4]

Figure 2a. Cervical Active Range of Motion Test.

participant's

head
flexed
rotated
resistance.

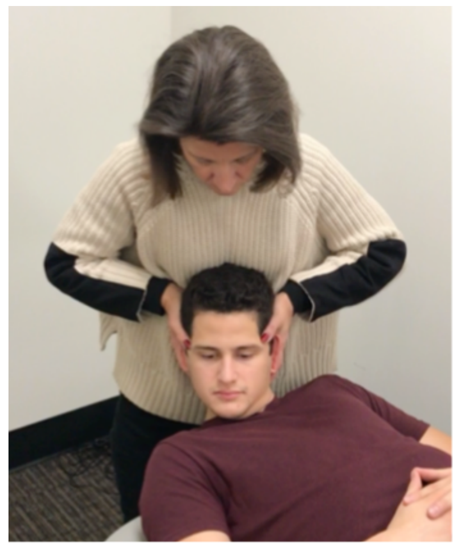


Figure 2b. Cervical Flexion Rotation

The neck was fully flexed with the occiput resting against the examiner's abdomen, and the modified CROM® was positioned at the middle of the top of the to measure cervical rotation in a fully position. The examiner passively the head to the right until he felt firm

The Cervical Flexion Rotation Test (CFRT) is a valid and reliable test used to identify impaired upper cervical mobility (Figure 2b).[8] The CFRT was measured as described by Blanpied et al[8] using a modified CROM® to obtain each measurement. A second examiner recorded the goniometric measure. Two trials were performed in each direction with the mean of the two trials recorded. Mean range of motion is reported to be 39-45° in healthy adults with an SEM of 2-3° and MDC of 4.7-7°.[8]

Glenohumeral Passive Range of Motion (GHPROM) internal rotation, external rotation, and horizontal adduction were measured bilaterally in supine with the scapula stabilized as described by Shanley et al[81]. Shoulder flexion was assessed in supine with the hips and knees flexed and the lateral border of his scapula firmly stabilized by the hand of the examiner as illustrated in Wilk et al.[100.] Two examiners performed each measurement with one examiner identifying end range and the other recording the measurement from the Microfet3 digital inclinometer (Hoggan Scientific, Salt Lake City, UT) (Figure 4). Examiners were blinded to hand dominance, and the primary examiner was blinded to the values. Two trials were taken for each motion and their average was recorded. Reliability of GHPROM measurement is excellent with an $ICC_{3,1}$ for intra-rater reliability of .95-.98, and an SEM of 2.0-6.7°.[18]

Figure 4. Glenohumeral Passive Range of Motion

Injury Tracking

Injury outcome measures were selected to capture patient-oriented outcomes that addressed both time-loss and patient reported pain and disability. Time-loss was recorded as any athlete exposure (AE) missed due to shoulder or elbow complaints. A time-loss *injury* was defined as any shoulder or elbow condition that resulted in inability to participate in baseball activities for > 7 days. Injury rate was calculated by the number of injuries per 1000 pitches, as this may be a better indicator of injury risk in pitchers.

Patient Reported Outcomes

The Disabilities of the Arm, Shoulder, and Hand is a region-specific patient reported outcome that measures upper extremity symptoms and disability.[3] The 4-item DASH Sports Module (DASHSM) captures an individual's level of disability in playing his or her sport- the lower the score on the DASHSM, the better the score. There is significant evidence that the DASH is a reliable, responsive, and valid measure in patients with shoulder or upper limb problems, however it does not target the shoulder and elbow specifically and is not sport specific.[3] However, it is quick and easy to complete for the respondent. Radwan et al[70] demonstrated a strong negative correlation between the Kerlan Jobe Orthopedic Clinic Score and the DASHSM ($r = -.825$, $p = .01$) and suggested a cutoff score of >12.6 best distinguished between injured and uninjured groups in Division III overhead athletes.[70]

The Functional Arm Scale for Throwers (FAST) is a region-specific and population specific patient reported outcome tool developed to measure health-related quality of life in throwing athletes. The FAST consists of 22 items and a 9-item Pitcher Module specific to baseball that may be interpreted independently. The FAST is converted to a 100 point scale with a higher score indicating greater pain and disability. Both the FAST and the Pitcher Module are reliable, valid, responsive, and able to discriminate between injured and uninjured players.[43] A FAST total cutoff score of 10.0 /100.0 had a sensitivity of .91 and specificity of .75, and a FAST Pitcher Module cutoff score of 10.0/100.0 had a sensitivity of .87 and specificity of .78 with accuracy of 85.1% and 87.6%, respectively.[43]

Pitchers completed all patient reported outcomes at baseline, and they completed the a FAST Pitcher Module every two weeks to measure pain and disability.

Data Reduction & Statistical Analyses

Means and standard deviations were calculated for each variable. Total glenohumeral rotation range of motion was calculated for each arm by adding the mean internal rotation and mean external scores. Difference scores were calculated between the dominant and non-dominant sides for Cervical Active Range of Motion Lateral Flexion and Rotation, the Cervical Flexion Rotation Test, and Glenohumeral Passive Range of Motion measures.

DASHSM and FAST Pitcher Module values were averaged across the season, and participants were considered "injured" for the analysis if time-loss was > 7 days, the DASHSM average score was >12.6, or the FAST Pitcher Module average score was >10. Data were not normally distributed, so differences in pre-season physical measures between Injured and Uninjured groups were analyzed using the Mann Whitney U test. ROC curves were generated variables with significance at p<.10 to plot Sensitivity, Specificity, and cutoff values in order to estimate the diagnostic utility of the measures as screening tools. Participants were dichotomized into "positive" and "negative" groups for the tests based on cutoff values that optimized Sensitivity, and Positive Predictive Values (PPV), Negative Predictive Values (NPV) and risk ratios (RR) were computed. Confidence intervals around the risk estimates were calculated to get a candid and realistic interpretation of the clinical meaning of these values in predicting injury. Multinomial logistic regression was performed to assess usefulness of each factor or a combination of factors in predicting the probability of injury.

Statistical analyses were performed with SPSS v.24 and Medcalc v.17.9 with an a priori significance level of p<.05 and minimal AUC of .70 for ROC analysis.

RESULTS

Forty-nine collegiate baseball pitchers (19.9 ±1.5 years, 187.0 ± 6.0 cm, 89.1 ± 12.1 kg) enrolled in the study. Of the 49 pitchers, time-loss data was collected on all 49. Patient-reported outcome analysis was based on 37 pitchers due to lack of compliance with in-season reporting by 12 pitchers. Thirty-eight pitchers (77.6%) were right hand dominant, and 67.3% played at the Division I level. Twenty-one pitchers (57%) reported a prior history of shoulder or elbow injury, and 34.7% reported that they pitched with arm pain in 2017.

Injury

Of the 49 pitchers enrolled in the study, 20.4% (10/49) suffered a shoulder or elbow injury that kept them from play for > 7 days (Table 1) with a total of 380 days lost. Injury incidence was .47/1000 pitches. Six players had elbow injuries, three had shoulder injuries, and one had both shoulder and elbow complaints. Additionally, 32.4% (12/37) of pitchers had an average Fast Pitcher Module score >10 across the season, and 18.9% (7/37) scored above 12.6 on the DASH Sports Module.

Table 1. Means and Standard Deviations for Outcome Measures

	n	Mean	SD
Time loss	n=49	7.2	17.8
FAST Pitcher Module Average	n=37	9.0	11.7
DASH Sports Module Average	n=37	8.1	11.7

Table 2. Physical Measures Mean Scores and Standard Deviation

	Uninjured n=39	Injured TL>7d n=10	p

Height (cm)	183.9	6.1	184.7	5.6	.760
Mass (kg)	88.5	12.3	91.5	11.3	.412
IKM°					
Relaxed	132.9	6.94	134.32	9.8	.687
Cued	138.0	6.97	139.77	10.5	.634
Flexion Rotation Test°					
Dominant	38.28	6.61	34.10	7.46	.028*
Non-dominant	38.68	5.21	36.55	7.82	.253
Difference	-.406	5.45	7.55	3.48	.320
Cervical Range of Motion°					
Flexion	64.56	9.86	58.00	13.23	.076
Extension	70.76	7.81	71.90	9.81	.599
Lateral Flexion					
Dominant	41.37	5.60	43.05	7.56	.582
Non-dominant	43.86	4.82	43.65	9.67	.599
Rotation					
Dominant	68.46	6.31	66.85	11.49	.485
Non-dominant	68.47	5.85	67.30	11.16	.384
Glenohumeral PROM°					
Internal Rotation					
Dominant	46.33	7.70	45.32	8.53	.501
Non-dominant	54.44	6.76	53.80	11.08	.855
Difference	-8.10	-8.48	8.64	9.46	.893
External Rotation					
Dominant	95.55	6.50	94.95	7.78	.705
Non-dominant	86.03	9.54	86.30	9.12	.836
Difference	9.52	8.65	8.25	9.01	.616
Flexion					

Dominant	133.59	12.10	133.90	11.01	.760
Non-dominant	131.92	11.58	129.87	13.08	.634
Difference	1.68	4.03	13.36	12.05	.855
Hor. Adduction					
Dominant	17.86	4.15	17.6	6.54	.533
Non-dominant	19.33	5.23	19.82	9.28	.779
Difference	-1.46	-2.20	8.28	5.02	.470

Time loss

All 49 participants were included in the time-loss analysis. Two pitchers left their team for reasons other than injury; however, they withdrew late in the season, had missed no time due to shoulder or elbow pain, and were included in the final analysis. The distribution of scores for the Cervical Flexion Rotation Test was significantly lower for the Injured group than for the Uninjured group (p=.028) with a mean difference of 4.2° (Table 2). For all other distributions, including the Inclinometric Kyphosis Measure, no significant differences were observed between the two groups, although Cervical Flexion Range of Motion approached significance (p=.076) with a mean difference of 6.6°. On multinomial regression, the Cervical Flexion Rotation Test was the primary independent predictor of whether a pitcher subsequently missed >7 days (P=.023, pseudo R^2 = .256).

The ROC curve (Fig. 5) shows the relationship between sensitivity and specificity for the Cervical Flexion Rotation Test. The area under the curve represents the ability of the test to discriminate between Injured and Uninjured pitchers. A cutoff score of < 39.25° for the dominant Cervical Flexion Rotation Test was able to discriminate between those pitchers who sustained a time-loss injury and those who did not. Diagnostic values are reported in Table 3. Ultimately, pitchers with <39.25° degrees had over 9 times greater risk of time-loss shoulder or elbow injury versus those with more mobility

(RR=9.38 (95% CI 1.28-68.49).

Figure 5. Dominant Cervical Flexion Rotation Test and Time-loss injury

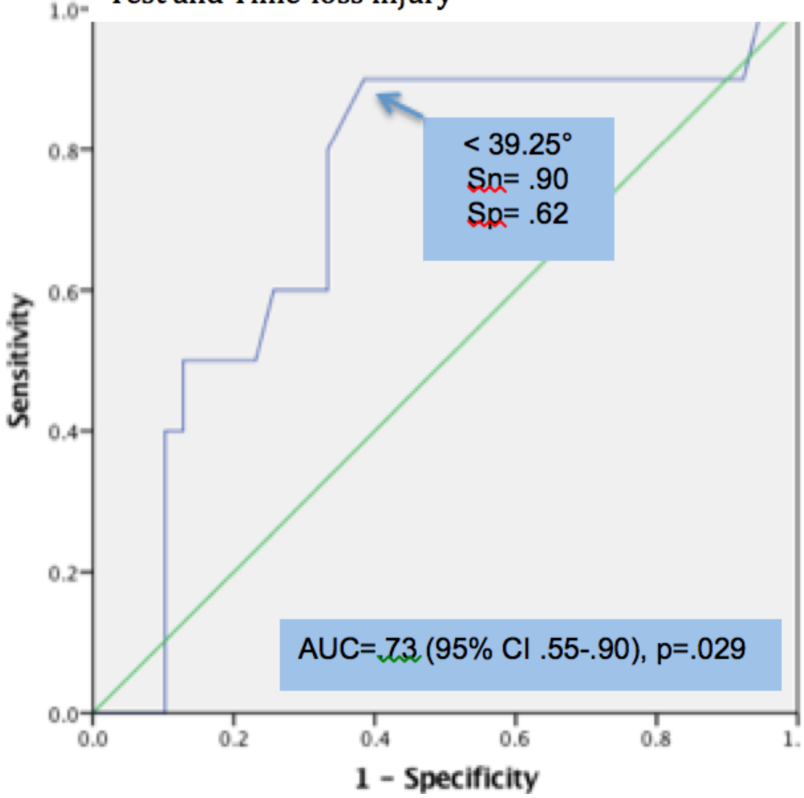


Table 3. Tests and Measures Predictive of Time loss Injury (95% CI)

Time loss >7 days					
n=49	**+LR (95% CI)**	**-LR (95% CI)**	**PPV (95% CI)**	**NPV (95% CI)**	**RR (95% CI)**
Cervical Flexion Rotation Test	2.37 (1.51-3.72)	.16 (.02-1.05)	38% (28-49%)	96% (78.6-99.4%)	9.38* (1.28-68.49)

* p< .05

FAST Pitcher Module

Distributions for dominant Cervical Flexion Rotation Test and Cervical Flexion Range of Motion differed significantly between the Injured group (>10 on the FAST

Pitcher Module score) and the Noninjured group (Table 5) Additionally, Weight and Glenohumeral External Rotation Difference were different between the two groups. The ROC curve analysis showed at dominant side Cervical Flexion Rotation Test (AUC=.73, 95%CI .54-.92, p=.030), Cervical Flexion Range of Motion (AUC=.76, 95% CI .60-.92, p=.014), mass (AUC=.78, 95%CI .60-.96, p=.008), and Glenohumeral External Rotation Difference (AUC-.74, 95%CI .54-.94, p=.025) indicating an ability to discriminate between the two groups. Sensitivity, Specificity,

Table 4. Tests and Measures Predictive of Patient Reported Outcomes

	Sn	**Sp**	**+LR (95% CI)**	**-LR (95% CI)**	**PPV (95% CI)**	**NPV (95% CI)**	**RR (95% CI)**
FAST Pitcher Module Ave >10 n=37							
Dominant Cervical Flexion Rotation Test*	.82	.58	1.95 (1.15, 3.32)	.31 (.09-1.09)	47.62% (35.19-60.35)	88.24 % (66.99-96.52)	4.05* (1.02-16.04)
Cervical Flexion Range of Motion*	.91	.62	2.39 (1.41, 4.07)	.15 (.02, .91)	52.38% (39.65, 64.81)	94.12% (70.51, 99.07)	8.90* (1.27, 62.26)
Weight*	.91	.69	2.94 (1.60, 5.40)	.13 (.02, .81)	57.89% (3.10, 71.40)	94.44% (71.86, 99.12)	10.42* (1.14, 213.70)
Glenohumeral external rotation difference	.73	.58	1.74 (.98-3.09)	.47 (0.17-1.26)	45% (31.96-58.77)	83.33% (64.01-93.36)	2.70 (0.86-8.45)
DASH Sports Module Ave>10 n=37							

Height	.71	.63	1.92 (1.03-3.59)	.46 (0.18-1.18)	47.06 (32.01-62.67)	84.21 (66.04-93.60)	2.98 (.63-22.52)
Cervical Flexion Range of Motion	1.0	.58	2.38 (1.42-3.48)	.00 (.01-1.61)	35% (26.34-44.77)	100.00%	12.86 (.79-209.89)
Horizontal Adduction (Non)	1.0	.60	2.50 (1.46-3.70)	.00 (0.01-.55)	36.84% (27.34-47.48)	100.00%	14.25 (.87-232.71)

* p< .05

PPV, NPV, and Relative Risk for patient reported outcomes are reported in Table 4. Ultimately, pitchers with < 38.25° on the dominant Cervical Flexion Rotation Test had 4 times greater risk of shoulder or elbow pain and disability than those with more mobility, and pitchers with < 64° Cervical Flexion Range of Motion had almost 9 times greater risk. Heavier pitchers also had increased risk; a weight greater than 86.86 kg resulted in 10.42 times greater risk of pain and disability. A Glenohumeral External Rotation Difference of <11.75° increased the risk of shoulder pain and disability on the FAST Pitcher Module by 2.70 times.

<u>DASH Sports Module</u>

Distributions for Height, Non-dominant Cervical Rotation Range of Motion, Cervical Flexion Range of Motion, and non-dominant arm Horizontal Adduction differed significantly between the Injured and Noninjured groups.

In the ROC curve analysis, Height (AUC=.79, 95%CI . 59-.98, p=.02), Cervical Flexion Range of Motion (AUC=.78, 95%CI .58-.91, p=.05), and non-dominant arm Glenohumeral Horizontal Adduction (AUC-.75, 95%CI .60-.91, p=.04) were able to discriminate between the two groups. Pitchers who were taller than 71.87 inches, had <68° Cervical Flexion Range of Motion, and more than 6° side to side difference in

Glenohumeral Horizontal Adduction were 2.98, 12.86, and 14.25 time more likely to report pain and disability, respectively.

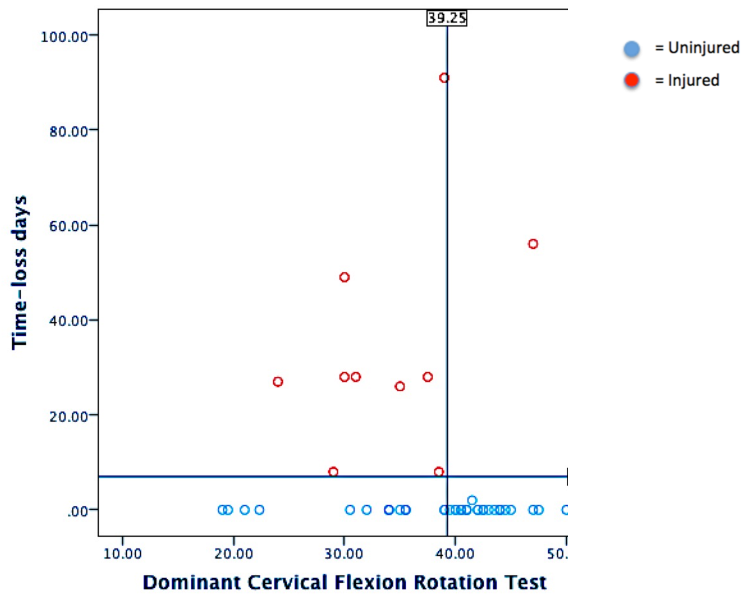
DISCUSSION

Main findings

The purpose of the study was to assess the ability of preseason posture and neck mobility measures to predict shoulder and elbow pain and disability in college baseball pitchers across a season. The most important finding in the study is that the preseason Cervical Flexion Rotation Test was associated with increased risk of a shoulder or elbow injury resulting in both time-loss and patient-reported pain and disability. Additionally, limited Cervical Flexion Range of Motion resulted in greater risk of self-reported pain and disability. This suggests that neck mobility plays a role in the etiology of shoulder and elbow pain in baseball pitchers.

Of the ten pitchers who suffered a time loss injury, all but one had a preseason dominant Cervical Flexion Rotation Test <39.25°(Figure 5).

Figure 6. Cervical Flexion Rotation Test and Time-loss Injury



The high Sensitivity and Negative Predictive Values suggest that the Cervical Flexion Rotation Test may have value as a screening test to identify players at lower versus higher risk of sustaining throwing-related shoulder and elbow injury. From a clinical perspective, with a general preseason injury risk of 20%, a pitcher below the cutoff would have a 37% risk of missing > 7 days with a shoulder or elbow condition, while a pitcher above the cutoff would have a risk of 4%. Similarly, Cervical Flexion Range of Motion < 64° identified pitchers at risk of self-reported pain and disability on the FAST Pitcher Module. Again, high Sensitivity and Negative Predictive Values indicate that this test may be useful in stratifying pitchers according to low and high risk. With a 32% preseason risk of developing pain and disability, a pitcher below the cutoff would have a post-test probability of injury of 53%. A pitcher with >64° would have a resultant risk of 7%. These tests could be components of a risk stratification strategy to target those players most at risk with interventions to improve impairments related to injury risk with an aim of reducing injury rates.

Another interesting result was the relationship between higher weight and increased risk of patient reported pain and disability. Chalmers et al[11] reported a similar finding in that Major League Baseball players who had undergone ulnar collateral ligament reconstruction were heavier than their non-injured counterparts. One possible explanation is that heavier players throw harder resulting in increased forces through the shoulder and elbow, but this would likely result in structural or time-loss injury. Interestingly, there is emerging evidence that adiposity is linked to musculoskeletal pain complaints, but without an assessment of body composition, we cannot infer that this played a role in pain and disability.

Several other variables did appear to be related to increased risk of self-reported pain and disability. Glenohumeral External Rotation Difference <11.75°, Height < 71.88 inches, and non-dominant Horizontal Adduction of <19.75° all increased the risk of self-reported shoulder pain and disability, but the confidence intervals for the risk ratios spanned "one" indicating the possibility that the increased risk is actually zero.

The results of this study support the premise that the cervical spine plays a role in the etiology of throwing-related shoulder and elbow injury. However, the hypothesis that limitations in non-dominant neck rotation mobility interfere with target acquisition with resultant alterations in throwing mechanics was not borne out. In fact, it was limited the dominant side Cervical Flexion Rotation Test that corresponded with shoulder and elbow injury. While the underpinnings of this relationship are unclear, limited neck mobility may influence the pitcher's ability to maintain head stability during the later phases of the pitching motion. For a right handed pitcher, during the late cocking phase, acceleration, and follow through, the trunk rapidly flexes and rotates and laterally flexes to the left on a fixed head (creating relative cervical extension and right rotation and lateral flexion). A reduction in upper cervical rotation mobility would necessitate compensatory mid-cervical rotation (coupled with lateral flexion and extension). These combined motions may decrease space for the nerve roots in the intervertebral foramina with consequent myotomal changes that alter the strength and endurance of the scapular and glenohumeral muscles.[50] Dilorenzo et al[22] noted that cervical mobility restrictions could inhibit efficient execution of the coordinated movements necessary for successful pitching and linked cervical dysfunction with athletic elbow injuries. This is consistent with the generally accepted concept that proximal dysfunction alters distal function. With respect to the results of our study, these explanations are speculative and etiology of the relationship observed in this study needs further investigation.

Strengths

This research fills an important gap in the risk profile for baseball pitchers, as this is the first study to investigate the relationship between neck mobility and shoulder and elbow injury. The magnitude of the increased risk indicates that neck mobility impairments have a place alongside other previously identified risk factors as part of a screening strategy. Several authors have reported that limitations in glenohumeral mobility increase the risk of shoulder and elbow injury.[81,99,100] Preseason glenohumeral internal rotation and an internal rotation deficit >13, horizontal adduction >15 have been reported to increase shoulder and elbow injury risk by 4-6 times in junior and high school baseball players.[81,85] At the professional level, Wilk et al[99] found nearly three times increased risk of elbow injury in pitchers with ≥ 5° deficit in dominant shoulder flexion or >5° total rotation deficit. The same authors reported over 2 times increased risk of shoulder injury in pitchers with <5° difference in glenohumeral external rotation.[100] In the current study, external rotation difference was associated with increased risk of self-reported shoulder and elbow injury, but the possibility that this relationship was due to chance could not be ruled out. Sakata et al[77] recently reported that a more kyphotic posture (> 30°) resulted in 2.5 times increased odds of medial elbow injury in youth baseball players. In our study, posture and shoulder range of motion were not significantly associated with throwing-related injury. This could be due to differences in the study population and limited sample size. The addition of neck mobility measures to previously identified risk factors is a step forward on the path to a multifactorial risk profile.

Up to this point, most prospective studies regarding throwing-related injury risk have defined injury only in terms of time-loss. Kerr et al[48] reported that baseball had the highest percentage of non-time-loss injury of all college sports from 2009-2014 indicating that players often continue to participate while suffering some level of pain and disability. In this study, the use of both time-loss and patient reported outcomes to define injury provides a more comprehensive picture of the burden of disability from shoulder and elbow conditions in college pitchers. The fact that limited neck mobility was predictive of both time-loss and patient reported outcome lends even more credibility to clinical utility of inclusion neck mobility measures with this population.

Limitations

The results of this study should be interpreted conservatively. While the study was adequately powered for the primary question, a larger sample would have narrowed confidence intervals and obtained a more precise estimate of the relative risk attributable to limited neck mobility. We were also unable to tease out distinctions between shoulder and elbow injury, and several independent variables approached statistical significance. A larger sample would have had adequate power to detect potential relationships and interactions between factors.

Prior research suggests that each competition level may have a unique risk profile; our results may be specific to college pitchers, so it is premature to extrapolate to different age groups. Additionally, enrollment of pitchers from only three schools in one region of the United States limits the generalizability of results.

Finally, although we found that neck mobility predicted injury risk, we cannot assume that improving neck mobility will lead to reduced injury rates, and this hypothesis should be tested with a well designed intervention study.

Delimitations

The definition of a time-loss injury as one that resulted in >7 days lost was chosen for several reasons. Initially, the injury definition was consistent with that of the recent study by Shitara et al[85]. Second, visual inspection of our data suggested that those who missed >7 days were a distinct group. Finally, from a practical standpoint, missing more than a week of play during a relatively short season represents a significant impact on the pitcher and the team. Interestingly, pitchers who missed > 7 days missed ended up missing at least 21 days, which is consistent with prior research.[54] Therefore, our definition seemed to appropriately measure a significant time-loss injury.

Future Directions

To further understand neck mobility in the context of baseball injury risk, broader validation of the results is necessary in order to generalize across age and competition levels. Injury outcomes should ideally include time-loss, non-time-loss and patient-reported outcomes in order to illustrate the full burden of shoulder and elbow injuries on baseball pitchers. Additionally, neck mobility should be assessed in the context of a mixed-model multifactorial analysis to identify predictors and interactions that are sufficiently strong to warrant an injury prevention intervention. Ultimately, a practical, multifaceted method of risk profiling for baseball pitchers would lead to design and implementation of effective interventions to reduce the incidence of serious throwing-related upper extremity injury.

CONCLUSION

Preseason cervical mobility predicted the development of shoulder and elbow time-loss injury and self-reported pain and disability in college baseball pitchers over the course of a season. The Cervical Flexion Rotation Test and Cervical Flexion Range of Motion demonstrated high sensitivity and negative predictive value, and therefore may be useful screening tools in developing a risk profile for individual pitchers.

CHAPTER V

In-Season Changes in Neck and Shoulder Mobility Measures in College Baseball Pitchers

Research Question:

Do neck and shoulder mobility measures in college baseball pitchers change during the season, and are those changes different between injured and uninjured pitchers?

Target Journal: Sports Health

ABSTRACT

Background: Shoulder and neck mobility measures have been identified as risk factors for throwing-related shoulder and elbow injury in baseball pitchers. Prior research demonstrates that physical measures change across a baseball season, but injury risk assessment has thus far relied solely on preseason measures. **Purpose**: To determine whether neck and shoulder mobility measures in college baseball pitchers change across a season and if variability in measures differs between injured and uninjured groups. **Design**: Cohort study. **Methods:** Forty-nine healthy college baseball pitchers (19.92 ±1.48 years, 187.04 ±6.02 cm, 89.14 ± 12.08 kg) were enrolled prior to the 2018 college season. Posture, neck mobility, and glenohumeral passive range of motion were measured during preseason and at mid-season using the Inclinometric Kyphosis Measure (IKM), CROM®, Cervical Flexion Rotation Test, and digital inclinometer, respectively. Time-loss (days lost to shoulder or elbow injury) and pitch counts were recorded, and pitchers completed the Functional Arm Scale for Throwers (FAST) Pitcher Module throughout the season. Pitchers were dichotomized into Injured and Uninjured groups based on time-loss > 7 days or FAST Pitcher Module score >10. Preseason and mid-season measures were compared with repeated-measures MANCOVA with pitch count as a covariate, and one-Way ANOVA was performed to evaluate group differences. **Results**: Three pitchers withdrew at mid-season testing. Eight pitchers (17.3%) sustained a time-loss injury, and ten had a FASTPM score > 10. An overall change in mobility was observed from preseason to midseason (p=.011). There were significant decreases in bilateral Cervical Sidebending motion (p=.000; p=.009), Cervical Flexion motion (p=.023), and the Cued IKM (p=.001). There were no group differences in variability for time-loss or the FASTPM. **Conclusions**: Neck mobility significantly decreased from preseason to midseason in a cohort of college baseball pitchers. Injured pitchers tended to display less cervical mobility across the season.

Key terms: posture, cervical spine, elbow, throwing

Word count: 295

INTRODUCTION

Despite efforts at prevention, the incidence and prevalence of serious shoulder and elbow injuries in baseball pitchers have steadily increased over the past three decades with the most concerning trends occurring in the youth and high school age groups.[17,55,68] The drastic increase speaks to the need for development and implementation of robust, effective injury prevention programs (IPPs), however, evidence-based IPPs are still in the development and early implementation stages in baseball. Potentially important risk factors such as neck mobility have not been thoroughly explored, and researchers have only recently begun to assess the efficacy of exercise-based prevention programs for throwing-related upper extremity injuries..[77,86]

Prospective investigation of injury risk in baseball has been marked by the study of preseason measures in an attempt to identify players at greater risk of injury.[94,100] Through preseason testing, researchers have identified a number of modifiable, intrinsic risk factors including limited glenohumeral ROM[81,99,100], elbow extension ROM limitation[76], increased thoracic kyphosis angle[76], and rotator cuff muscle weakness.[24] However, several authors have demonstrated that these preseason measures used to assess injury risk change both acutely and over the course of a baseball season. Reinold et al[73] and Case et al[33] found that glenohumeral range of motion changed after a single bout of throwing in college and professional pitchers, and these changes were still evident 24 hours post throwing. Shanley et al[83], Freehill et al[33], and Laudner et al[49], and all reported changes in glenohumeral range of motion cumulatively across one or more baseball seasons in high school, college, and professional pitchers. Similarly, McHugh et al[56] found that in high school pitchers, supraspinatus strength decreased during the season, and this was particularly the case for high volume pitchers. These examples suggest that the construct of “injury risk” in baseball is dynamic and lend credence to the idea that a pitcher who does not present with a risk factor in the preseason may acquire that risk with repeated exposure during a season. Likewise, the influence of a risk factor may be blunted as a pitcher adapts to repeated bouts of throwing. Currently, the variability in neck mobility measures across a season in baseball pitchers is unknown.

The concept of dynamic injury risk is not novel. In 2007, Meeuwisse et al[57] introduced a dynamic recursive model of injury etiology proposing that risk factors interact with repeated participation in sport to dynamically alter risk of athletic injury over time. If the current approach assumes that risk factors are stable measures, it may not allow for the best management of baseball injuries over the entirety of a season. Patterns of change observed from measurements collected at multiple time points may provide a more comprehensive picture for risk assessment and prevention purposes. Yet, all prospective studies of baseball injury risk to date have relied solely on preseason measurements, and only one study considered the effects of a recent throwing bout.[81] Therefore, the purpose of the study was to determine if measures of neck and shoulder mobility in college baseball pitchers change during a season and whether variability in measures differs between injured and uninjured groups.

METHODS

A prospective study was conducted during a single college baseball season to pursue the purposes of this study. The university's Institutional Review Board approved the human subjects protocol prior to participant recruitment, and all participants provided written informed consent.

Participants

Pitchers were recruited from two NCAA Division 1 and one NCAA Division 3 college baseball teams in January 2018 and were screened for eligibility at the time of consent. To be eligible, pitchers had to be age 18 years or older and medically cleared to participate in baseball activities. Pitchers were excluded from the study if they were younger than 18 or had a current shoulder or elbow injury which precluded participation in baseball activities. Based on consideration of prior research [23,91], an α level of .05, power= .80, and a correlation coefficient of r=.448 from preliminary data, we determined an a-priori required sample size of 37 (MedCalc for Windows, version 17.0 (MedCalc Software, Ostend, Belgium).

Data collection

During early preseason, pitchers completed an intake questionnaire and baseline patient reported outcome measures. The Intake Questionnaire gathered information regarding age, hand dominance, and shoulder and elbow injury history. Posture, neck mobility, and bilateral glenohumeral passive range of motion were measured as described below. Measurements took place on a day when players had not pitched within the past three days. Throughout the season, participants completed a weekly online questionnaire to assess pain and disability, and the team athletic trainer tracked time-loss and game and bullpen pitch counts (Figure 1).

Eight to ten weeks after the preseason data collection, a second, identical test session was completed during mid-season.

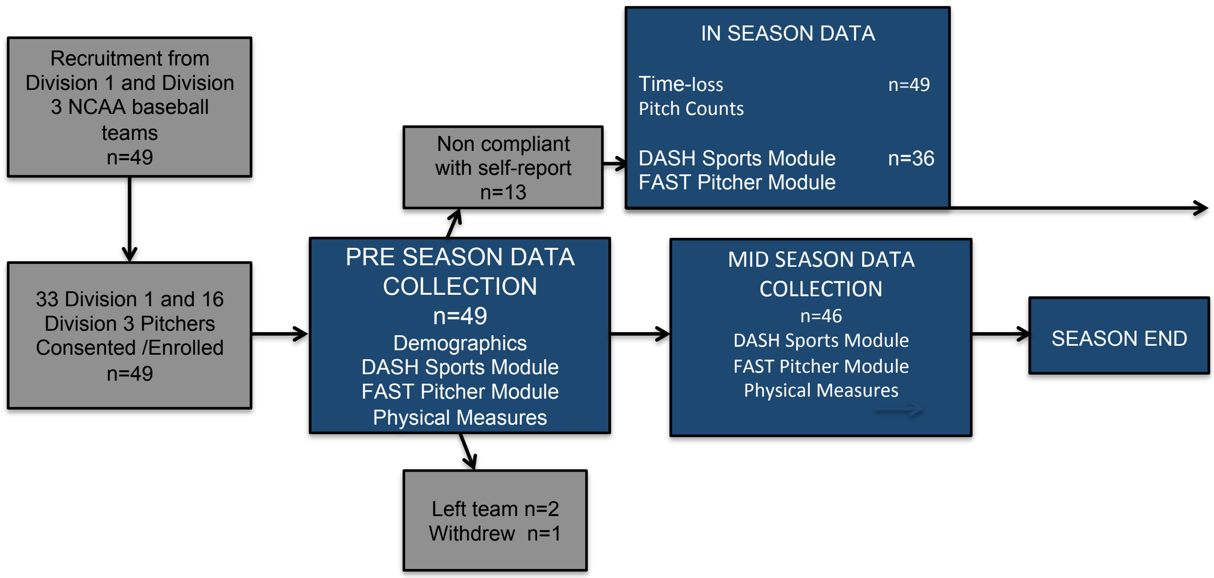


Figure 1. Flow chart of cohort study

Examiners

A licensed physical therapist/athletic trainer and four trained graduate Doctor of Physical Therapy students collected all physical measures and patient reported outcomes. The same rater recorded all measures. The team athletic trainers collected time-loss and pitch count data, but they did not have access to the pitchers' patient reported outcomes during the season.

Physical Measures

The Inclinometric Kyphosis Measure (IKM) is a reliable and valid clinical measure of posture.[20] Each pitcher was measured in both usual posture (relaxed) and best posture (cued) using the Microfet3 digital inclinometer (Hoggan Scientific, Salt Lake City, UT) as outlined in Devaney et al.[20-2] In relaxed posture, the examiner first aligned the inclinometer vertically along the lower lumbar spinous processes to measure the thoracolumbar angle. (Figure 2a). The inclinometer was then aligned vertically along the upper mid-thoracic spinous processes to measure the cervicothoracic angle (Figure 2b). The two recorded angles were added together, and their sum was subtracted from 180° to arrive at a measure of dorsal kyphosis. Two trials were performed and the mean measure was recorded. The examiner then instructed the pitcher to “stand straight and tall” and repeated the measurement for the cued condition. Intra-rater reliability of the IKM has been demonstrated in healthy adults ($ICC_{3,1}$= .98 (.94-.99), SEM= 1.28°, MDC= 3.55°) (Devaney et al unpublished data, 2017) and in patients with orthopedic conditions in both the relaxed ($ICC_{3,1}$= .91-.94, SEM=3°, MDC=8-10°).[20]

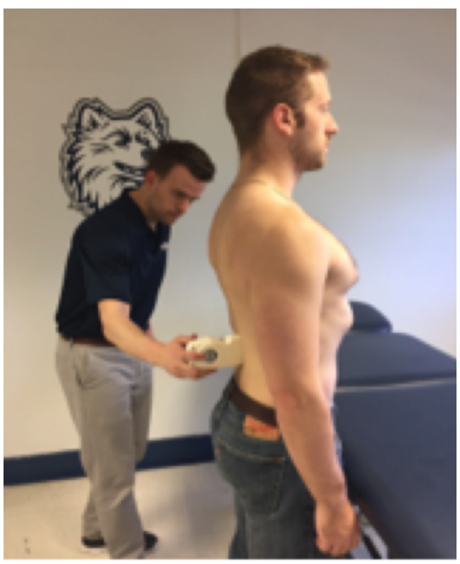


Figure 2a. Inclinometric Kyphosis Measure (Thoracolumbar angle). While maintaining light contact with the skin, the examiner moved the inclinometer superiorly along the spine until the curve first reversed and recorded the angle in degrees

Figure 2b. **Inclinometric Kyphosis Measure (Cervicothoracic angle).** While maintaining light contact with the skin, the examiner then moved the inclinometer superiorly along the spine until the curve first reversed and recorded the angle in degrees

Cervical Active Range of Motion (CAROM) was measured in six directions (flexion, extension, right/left lateral flexion, and right/left rotation) with the CROM® device (Performance Attainment Associates, Roseville, MN) as described by Audette et al[4] (Figure 3a). Prior to measurement, the examiner demonstrated the 6 cervical motions to be performed, and participants performed a familiarization trial of each motion. Each participant then performed two trials of each motion through a comfortable yet complete range, and the mean of the two scores was recorded. The CROM® is reliable across the 6 movements with an ICC =.93-.98, SEM =1.6°-2.8°, and MDC=3.6°-6.5°.[4]

Figure 3a. Cervical Active Range of Motion

participant's
abdomen, and
middle of
rotation in a
rotated
resistance.

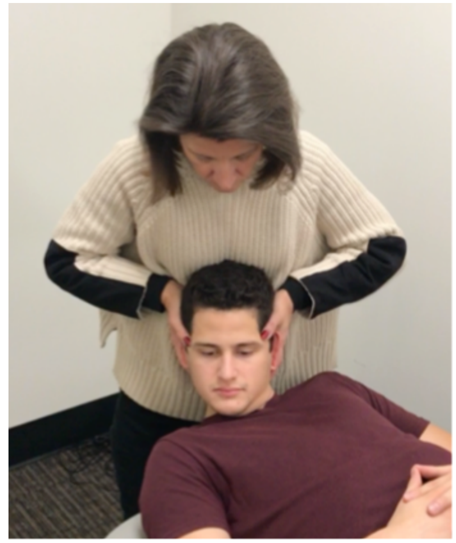


Figure 3b.Cervical Flexion RotationTest.
The neck was fully flexed with the
occiput resting against the examiner's
the modified CROM® was positioned at the
the top of the head to measure cervical
fully flexed position. The examiner passively
the head to the right until he felt firm

The Cervical Flexion Rotation Test (CFRT) is a valid and reliable test used to identify impaired upper cervical mobility (Figure 3b).[8] The CFRT was measured as described by Blanpied et al[8] using a modified CROM® to obtain each measurement. The cervical spine was fully flexed with participant's occiput resting against the examiner's abdomen, and the modified CROM® was positioned at the middle of the top of the head to measure cervical rotation in a fully flexed position. The examiner passively rotated the head to the right until he felt firm resistance. A second examiner recorded the goniometric measure. Two trials were performed in each direction with the mean of the two trials recorded. Mean range of motion is reported to be 39-45° in healthy adults with an SEM of 2-3° and MDC of 4.7-7°.[8]

Glenohumeral Passive Range of Motion (PROM) was measured bilaterally in supine with the scapula stabilized as described by Shanley et al[81](Figure 4). Shoulder flexion was assessed in supine with the hips and knees flexed and the lateral border of his scapula firmly stabilized by the hand of the examiner as illustrated in Wilk et al.[100.] Each pitcher was measured for flexion, external and internal shoulder rotation, and horizontal adduction using a Microfet3 digital inclinometer (Hoggan Scientific, Salt Lake City, UT) (Figure 4). Examiners were blinded to hand dominance, and the primary examiner was blinded to the values. Two trials were taken for each motion and their average was recorded. Reliability of glenohumeral PROM measurement is excellent with an $ICC_{3,1}$ for intra-rater reliability of .95-.98, and an SEM of 2.0-6.7°.[18]

a b c

Figure 4. Glenohumeral Passive Range of Motion. a. Internal rotation. b. Flexion c. Horizontal Adduction

Injury Tracking

Injury outcome measures were selected to capture patient-oriented outcomes that addressed both time-loss and patient-reported pain and disability. Time-loss was recorded as any athlete exposure (AE) missed due to shoulder or elbow complaints. A time-loss *injury* was defined as any shoulder or elbow condition that resulted in inability to participate for > 7 days. Injury rate was calculated by dividing the number of injuries by total number of game pitches and reported as number of injuries per 1000 pitches, as this may be a better indicator of injury risk in pitchers.[94]

Patient-Reported Outcomes

The Functional Arm Scale for Throwers (FAST) is a region-specific and baseball specific patient-reported outcome tool developed to measure health-related quality of life in throwing athletes. The FAST consists of 22 items and a 9-item Pitcher Module that may be interpreted independently. The FAST is converted to a 100-point scale with a higher score indicating greater pain and disability. Both the FAST and the Pitcher Module are reliable, valid, responsive, and able to discriminate between injured and uninjured players.[43] A FAST total cutoff score of 10.0 /100.0 had a sensitivity of .91 and specificity of .75, and a FAST Pitcher Module cutoff score of 10.0/100.0 had a sensitivity of .87 and specificity of .78 with accuracy of 85.1% and 87.6%, respectively.[43]

Pitchers completed all patient reported outcomes at baseline and mid-season testing, and they completed the FAST Pitcher Module every two weeks to measure pain and disability.

Data Reduction & Statistical Analyses

Means and standard deviations were calculated for each variable. Total glenohumeral rotation range of motion was calculated for each arm by adding the mean internal and external rotation scores. Side-to-side differences were calculated between the dominant and non-dominant sides for Cervical Active Range of Motion Lateral Flexion and Rotation, the Cervical Flexion Rotation Test, and Glenohumeral Passive Range of Motion measures. FAST Pitcher Module values were averaged across the season, and participants were considered “injured” for the time-loss analysis if time-loss was > 7 days. For the patient-reported outcome, a separate analyses was run and a pitcher was considered “injured” if the FAST Pitcher Module average score was >10.

Repeated measures MANCOVA was performed to assess significant differences in measures from preseason to mid-season. Change scores were then calculated for each measure from preseason to mid-season, and the change scores were analyzed with a one-way ANCOVA to explore group differences with pitch count as a covariate. Statistical analyses were performed with SPSS v.24 and Medcalc v. 17.9 with an a priori significance level of $p<.05$.

RESULTS

Forty-nine collegiate baseball pitchers enrolled in the study and were measured during preseason. Of the 49, three chose to not participate in mid-season testing leaving a cohort of 46 pitchers for the comparative analysis (19.9 ±1.5 years, 183.9 ±6.5 cm, 89.4 ± 11.8 kg). Thirty-six pitchers (78.3%) were right hand dominant, and 67.3% played at the Division I level. Nineteen pitchers (41%) reported a prior history of shoulder or elbow injury, and 32.6% reported that they pitched with arm pain in 2017. Over the course of the season, 17.4% (8/46) suffered a shoulder or elbow injury that kept them from play for > 7 days (injury incidence .37 injuries per 1000 pitches) for a total of 338 days lost. Five players had elbow injuries, two had shoulder injuries, and one had both shoulder and elbow complaints.Ten players scored > 10 on the FAST Pitcher Module which indicated self-reported pain and disability.

Change in physical measures from Preseason to Mid-season

The multivariate analysis of all physical measures was significant indicating that there was an overall change in the mobility characteristics of the pitchers from preseason to mid-season ($p=.011$). As compared with preseason values, mean mid-season measures were significantly less for dominant and non-dominant Cervical Sidebending ROM ($F= 31.385$, $p=.000$; $F= 7.557$, $p=.009$), Cervical Flexion Range of Motion ($F= 5.551$, $p=.023$), and the Cued IKM ($F=12.147$, $p=.025$)(Table 1). There were no significant differences in GHROM measures, nor was there a significant interaction between pitch volume and time (p>.05).

Table 1. Preseason and Mid-season Physical Measures (n=46)

Measure	Preseason Mean° ± SD	Mid-season Mean° ± SD	Change Mean° ± SD
CFRT Dom	37.6 ± 7.6	38.2 **±6.5**	0.6 **±7.3**
CFRT Non	38.5 ± 7.5	37.1 **±7.3**	-1.4 **±9.9**
CFRT Difference	-0.9 ± 7.6	1.1 **± 8.0**	2.0 **± 11.5**
CROM Flexion	62.9 ± 12.8	59.2 **±11.4**	-3.7 **± 10.6***
CROM Extension	71.3 ± 9.6	69.9 **± 9.4**	-1.4 **± 6.7**
CROM Sidebend Dom	41.8 ± 7.4	37.7 **±7.3**	-4.1* **± 5.0**
CROM Sidebend Non	43.8 ± 9.1	40.7 **±6.7**	-3.0* **± 7.5**
CROM Rotation Dom	68.1 ± 10.8	66.6 **±9.7**	-1.5 **±9.1**
CROM Rotation Non	68.2 ± 10.4	68.6 **±7.2**	0.4 **± 9.3**
IKM Relaxed	132.9 ± 8.9	132.0 **± 9.5**	-0.9 **±4.8**
IKM Cued	138.3 ± 9.7	136.3 **±10.1**	-2.0 **±5.9**
IKM Difference	4.3 ± 4.0	**4.8± 4.1**	0.5 **±3.5**
GHIR Dom	46.0 ± 8.2	46.4 **±8.9**	0.4 **±6.2**
GHIR Non	54.4 ± 10.6	56.0 **±10.4**	1.6 **± 8.9**
GHER Dom	95.6 ± 7.7	95.2 **± 8.2**	-0.3 **±4.3**
GHER Non	85.8 ± 9.1	87.1 **±9.4**	1.3 **±7.4**
GHFLEX Dom	133.9 ± 11.1	130.5 **±** 9.4	-3.4 **±12.7**
GHFLEX Non	131.8 ± 12.8	129.2 **±11.4**	-2.6 **±10.2**
GHHA Dom	17.6 ± 6.1	17.3 **±5.4**	-0.3 **±6.0**
GHHA Non	19.3 ± 8.8	19.8 **± 6.4**	0.5 **±7.3**
GH TROM Dom	141.6 ± 10.1	141.6 **±11.3**	-.1 **±6.7**

GHTROM Non	140.2 ± 12.6	143.1 **± 10.8**	-2.9 **± 9.6**
GHIR Difference	-8.4 ± 8.5	-9.6 **±** 7.1	-1.2 **±9.2**
GHER Difference	9.8 ± 8.1	8.2 **±9.5**	-1.6 **±8.1**
GHFLEX Difference	2.1 ± 12.3	1.3 **±14.6**	-0.8 **± 11.3**
GHHA Difference	-1.6 ± 7.8	-2.5 **±6.2**	-0.9 **± 7.4**
GH TROM Difference	1.4 **±** 9.0	-1.5 **±9.1**	2.8 **± 11.0**

*p<.05

Change Score Comparison: Injured versus Uninjured

There were no significant differences in change scores between injured and uninjured pitchers for time-loss (p=.901) or FAST-PM (p=.682)(Table 2).

Table 2. Change in Physical Measures in Injured (TL>7 days) and Uninjured Pitchers

	Uninjured n=38		Injured n=8	
	Mean difference°	SD	Mean difference°	SD
Height	-0.1	1.9	0.3	.8
Weight	0.4	5.4	3.6	3.2
IKM Relaxed	-0.6	4.9	-2.1	4.6
IKM Cued	-2.2	6.2	-1.3	4.1
IKM Difference	-0.4	3.4	0.9	3.8
CROM Flexion	-3.3	10.9	-5.3	9.6
CROM Extension	-1.5	6.8	-0.5	6.4
CROM Sidebend Dom	-4.0	5.3	-4.4	3.4
CROM Sidebend Non	-2.9	7.9	-3.5	5.3
CROM Rotation Dom	-0.7	9.1	-5.6	8.1
CROM Rotation Non	0.6	9.9	-0.9	6.2
CFRT Dom*	0.3	7.7	2.1	5.7
CFRT Non	-1.8	10.5	0.3	6.1
CFRT Difference	2.1	12.2	1.8	7.8
GH IR Dom	0.1	6.6	2.3	3.3

GH IR Non	0.9	9.4	5.1	5.3
GH ER Dom	0.1	4.1	-2.6	4.8
GH ER Non	1.2	7.8	1.5	6.2
GH Flexion Dom	-2.9	12.6	-5.6	13.7
GH Flexion Non	-2.5	8.9	-2.9	15.8
GH Horizontal Add Do	-0.7	6.0	1.1	6.0
GH Horiz Add Non	0.4	7.8	1.1	4.1
TROM Dom	0.2	7.0	-0.4	5.7
TROM Non	2.1	10.0	6.7	7.3
TROM Difference	-2.0	11.1	-7.0	10.3
IRDIFF	-0.9	9.8	-2.9	5.8
ERDIFF	-1.1	8.0	-4.2	8.5
FLEXDIFF	-0.4	11.7	-2.8	9.2
HADIFF	-1.1	7.9	0.0	4.6

Change in Injury Risk

Only one pitcher suffered a time-loss injury after the mid-season testing, so we were unable to determine whether a change in physical measures was related to subsequent injury risk.

DISCUSSION

Main Findings

The purpose of the study was to determine if measures of neck and shoulder mobility in college baseball pitchers change across a single season and whether variability in measures differs between injured and uninjured groups. The results demonstrate that the overall mobility profile of the pitchers changed from preseason to mid-season with a tendency toward reduced mobility as the season progressed.

Specifically, significant decreases were observed in bilateral cervical Sidebending ROM, Cervical Flexion ROM, and the Cued IKM indicating reduced mobility in the cervical and thoracic spine as the season progressed. While the variability in measures from pre- to mid-season did not differ between injured and uninjured groups, injured pitchers tended to display a greater reduction in cervical mobility than uninjured pitchers.

The importance of these findings is that changes in mobility across the season may alter injury risk for baseball pitchers. Decreased mobility has repeatedly been identified as a risk factor by prior researchers. Sakata et al[77] recently identified a more kyphotic posture and decreased elbow extension motion as risk factors for medial elbow injury in junior baseball players. Likewise, mobility deficits in glenohumeral range of motion have been identified as predictors of shoulder and elbow injury in youth[81], high school[85], and professional[99,100] baseball players. Finally, the results of the primary research question for this dissertation indicate that less cervical mobility is associated with injury risk. Reductions in cervical and thoracic mobility likely lead to compensatory alterations in pitching mechanics requiring greater contributions from the shoulder complex and increased strain on shoulder and elbow structures.

Interestingly, there were no differences in glenohumeral mobility from preseason to mid-season, but there is inconsistency in the literature regarding changes across a season. Thomas et al[91] found no significant changes in glenohumeral internal rotation, external rotation, or total rotation passive ROM in a small cohort of Division 1 college baseball players from pre- to post-season. On the other hand, Freehill et al[33] reported significant increases in glenohumeral external rotation and decreases in internal and total rotation ROM in Division III baseball pitchers over the course of the season. Inclusion of position players by Thomas et al[91] and the small sample of pitchers (6) in the Freehill et al[33] study make it difficult to draw meaningful conclusions. In our study, it may be that the mid-season time point was too soon to observe adaptive or deleterious changes in physical measures s opposed to those that might occur over a full season.

Variability in cervical mobility was not different between injured and uninjured groups, although we observed a pattern of greater decreases in mobility in the time-loss injury group. Additionally, change scores were not associated with pitch volume. Similarly, Freehill et al[33] also found that changes in shoulder ROM parameters were independent of extrinsic risk factors such as innings pitched, pitch count, and pitch type.

Since most pitchers were injured prior to mid-season testing, the group differences are based on retrospective analysis. However, the timing of the injuries emphasizes the importance of preseason measures in assessing injury risk in baseball pitchers and calls into question the value of mid-season measures given the relatively short college season. The change in mobility measures is still relevant, though, as college players move from the NCAA to summer league seasons and may sustain injuries with continued play. This may even more important at the professional level seasons where are at least twice as long as a college season.

LIMITATIONS

The time period between pre- and mid-season measurements was relatively short at only 8-10 weeks. We chose to measure mid-season in an attempt to discern whether mid-season measurements were associated with subsequent injury risk. We were unable to determine this since only one pitcher was injured after mid-season, nor could we analyze the relationship between a variability in measures and subsequent injury. While sample size was adequate to detect changes in some physical measures, others approached significance and may have varied with a more extensive sample. Moreover, with only eight injured pitchers, the study was underpowered to detect group differences in variability. Additionally, the inclusion of both Division 1 and Division III pitchers may have affected the results, as the exposure differs between the two competition levels. Longitudinal studies that follow a pitcher over the course of a longer or multiple seasons may offer a more useful explanation as to how changing variables affect injury risk.

Prior research suggests that each competition level has a unique risk profile. In this case, our results are likely specific to college pitchers given the length of the season, so it is premature to extrapolate to different competition levels. Additionally, enrollment of pitchers from only three schools in one region of the United States limits the generalizability of results. Finally, the change scores should be interpreted with caution as the magnitude of some scores were within the standard error of measurement.

FUTURE DIRECTIONS

Future research on the practical use of physical measures to predict injury risk should take into account the potential for these measures to change across time. Multicenter longitudinal research that is adequately powered to detect group differences and allow for recognition of patterns of change should inform clinicians and researchers alike in optimal timing of delivery of prevention strategies.

CONCLUSION

In a cohort of college baseball pitchers, neck mobility measures changed significantly over the course of a season, but no differences in variability of the measures were observed between injured and uninjured groups. Given that preseason neck mobility has been identified as a risk factor for shoulder and elbow injury, this suggests that future study of throwing-related injury risk should employ measurements at multiple time points in order to capture the dynamic nature of risk.

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